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PROCESSING AND BREEDING OF IMPROVED ALTERNATIVE WHEATS

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PROCESSING AND BREEDING OF IMPROVED ALTERNATIVE WHEATS

FINAL REPORT
(April 1, 1998 – December 31, 2001)

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ABSTRACT

An awnless spring spelt wheat with winter spelt protein profile resulted in the selection of a potential cultivar. The line 99SPELT9 completed a first year of Registration Test evaluation in 2001. This line is higher-yielding than CDC Bavaria, stronger-strawed, earlier maturing and higher in protein content. A number of promising follow-up lines are also under advanced testing. Breeding populations were initiated with the objective of further reducing the straw-length and lodging susceptibility of spelt wheat. We succeeded in developing a prototype emme x durum baking wheat. The lines in question combine loaf volumes equal to those obtained from CWRS wheat with the high-lutein content of CWAD wheat. Partially-threshable einkorn wheat lines with desirable flavour and cake quality were selected during the course of this project. Populations were initiated to improve the yield level of partially-threshable einkorn wheat. The first cycle of crosses did were not higher-yielding than the check cultivar. Back-crossed material was head-rowed in 2001 and could be yield-tested in 2002. Semidwarf puffing wheat lines with very large seed (65-70 mg) were developed. The initial selections were lower-yielding due to poor leaf disease reactions. However, follow-up crosses to develop rice-shaped puffing wheat have resulted in the selection of 20 elite lines in 2001.

The starch and protein characteristics of alternative wheats were studied to better determine their potential end-uses. Alternative wheat starches had a wide range of characteristics, reflecting potentially different end-uses. Einkorn wheat exhibited unique starch characteristics and had high protein and carotene contents and low gluten strength. Baked products made from Spelt, Einkorn and Emmer wheat. Puffing wheats were subjected to puffing tests and cereal flake processing. The resulting cereal flakes and puffed grains had a favorable taste. Spelt wheat exhibited good bread baking quality and potential for noodle and pasta production. The poor baking quality of Emmer wheat has been improved in Emmer/Durum derivatives. The quality of Einkorn cookie and cakes has been improved after selection against an undesirable after-taste.

EXECUTIVE SUMMARY

A breeding project to develop an awnless spring spelt wheat with winter spelt protein profile resulted in the selection of a potential cultivar. The line 99SPELT9 completed a first year of Registration Test evaluation in 2001. This line is, on average, ~10% higher-yielding than CDC Bavaria, stronger-strawed, earlier maturing and had a ~1% higher protein content. 99SPELT9 has a winter spelt protein profile and weaker gluten than CDC Bavaria. A number of promising follow-up lines are also under advanced testing. Breeding populations were initiated with the objective of further reducing the straw-length and lodging susceptibility of spelt wheat. We succeeded in developing a prototype emmer/durum baking wheat. The lines in question combine loaf volumes equal to those obtained from CWRS wheat with the high-lutein content of CWAD wheat. The initial lines are low-yielding and will have to be used as parents in order to develop lines with CWAD wheat yield potential. Partially-threshable einkorn wheat lines with desirable flavour and cake quality were selected during the course of this project. Populations were

initiated to improve the yield level of partially-threshable einkorn wheat. The first cycle of crosses did were not higher-yielding than the check cultivar. Back-crossed material was head-rowed in 2001 and could be yield-tested in 2002. Semidwarf puffing wheat lines with very large seed (65-70 mg) were developed. The initial selections were lower-yielding due to poor leaf disease reactions. However, follow-up crosses to develop rice-shaped puffing wheat have resulted in the selection of 20 elite lines in 2001.

Bread baking quality of Spelt wheat lines was determined using the optimized straight-dough procedure (AACC 10-10B). Dough from spelt wheat was slightly sticky but dough handling was improved during the dough fermentation period. Loaf volume was high in the breeding lines 2000Spelt20 and 2000Spelt29. Larger crumb grains were found in spelt bread. There was no significant difference in crust color among spelt wheat breads. Noodles from spelt wheats were comparable to Soft White Wheat noodles in overall texture profile, but spelt noodles were slightly less desirable with regards to hardness and gumminess. Cooking loss was slightly lower in spelt wheat noodles compared with Soft White Wheat noodles. Cooking loss was positively correlated to the starch content of flour samples. Pasta was prepared from selected spelt wheat lines, based on their yellowish flour color. Pasta stickiness was negatively related to cohesiveness and adhesiveness. Spelt pasta had a similar texture profile and comparable score to durum pasta in sensory evaluations. Spelt x common wheat lines had a good bread baking quality, comparable to that of the CWRS wheat cultivar, AC Barrie

Emmer bread was prepared using a straight-dough baking procedure with long fermentation time (AACC 10-09). Emmer/Durum wheat lines had longer mixing time to develop dough than Emmer19 (emmer parent) and Durum wheat. Most of emmer/durum wheat lines showed higher loaf volume than the durum parent (WB881). All breads had a yellowish crumb color compared with the common wheat commercial control bread. During the malting of Vernal emmer and accession Emmer19, the hydrolysis of starch and protein resulted in an increase in soluble carbohydrates, reducing sugars and soluble protein. Enzyme activities including ∀-amylase and proteolytic activity, were significantly increased by the malting process.

Einkorn cakes were similar in internal cell structure with control cakes and had creamy yellow crumb color. Einkorn cakes were very moist, tender and soft-textured. High acceptability was found for the line 2000EINK11 even though its cake had a slight after-taste. Overall, TM23, 98EINK31, 2000EINK11, 22 and 3 showed good baking quality with high scores in the sensory evaluation.

TECHNICAL REPORT

BACKGOUND AND OBJECTIVES

It was previously demonstrated that spring-type spelt, einkorn, Khorasan and emmer wheats are adapted to Saskatchewan growing conditions in our previous SADF project (R-92-CW-0791). These alternative wheats can be grown under organic conditions, a

growing niche market. Our main focus has been on spelt since this type of wheat already has a niche market. Two distinct types of spelt were identified, black-hulled or soft spelt and white-hulled or hard spelt. The end-use qualities of spelts differ. CDC Bavaria soft spring spelt was Iterim-Registered in Canada (1996-2001). Spelt wheat is nutritious (Abdel-Aal et al., 1995) and has a unique flavor when subjected to certain processing conditions (Abdel-Aal et al., 1997). Spelt wheat showed promise in particular cereal products, depending upon the cultivar. However, there is no information available on the biochemical constitution of these hulled wheats to assist in determining their end-use qualities. Utilization of einkorn flour in cookie and cake products has also shown promise. Although we identified a number of adapted emmer wheats, these were of poor quality.

The objectives of this project were to achieve the following goals:

(A) Select or breed:

(1) awnless spring spelt cultivar with winter spelt protein profile,
(2) einkorn with improved agronomic performance and marketability,
(3) emmer wheats suitable for baking and malting,
(4) semidwarf Khorasan wheat cultivar,

(B) Characterize and evaluate starch and protein profiles in alternative wheats as they relate to end-use,
(C) further evaluate the utilization of einkorn in cookie and cake products,
(D) evaluate the final food products in terms of acceptability, storageability and marketability.

EXPERIMENTAL METHODS

Grain quality and Processing experiments

Wheat Samples

Alternative wheats including, TM23 einkorn (diploid wheat), Vernal emmer and Dragon (PI211691) Khorasan (tetraploid wheats), PGR8801 hard spelt and CDC Bavaria soft spelt (hexaploid wheats) were evaluated for their starch characteristics and protein composition as they relate to their end-uses. Kyle durum and Katepwa CWRS wheat were included as conventional wheat checks.

Spring spelt wheat, Emmer/Durum derivatives, and einkorn wheat experimental lines grown in 1999 and 2000 were processed to evaluate their end-uses. Spelt wheats were evaluated for bread baking quality, noodle and pasta processing. Einkorn wheat lines were evaluated for cake and cookie baking quality. The Emmer/Durum derivatives wheat lines were evaluated for their bread baking quality. Four puffing wheat lines along with Kyle (CWAD) and CDC Dragon (Khorasan) were subjected to flake processing and puffing tests.

For milling into flour, grain samples were tempered over an 18 hr period based on the results of preliminary tempering experiments. Grains were milled on a Brabender Quadrumat Jr. Flour Mill (Brabender Co., South Hackensack, NJ, U.S.A.) equipped with a 6xx (233 micron) steel screen. Additional sifting of the bran fraction was performed on a 64-mesh sieve using a Ro-Tap sieve shaker (Tyler Co., Mentor, OH, U.S.A.) for 3 min. The average percent of recovery was 97.5% for spelt wheats, 97.9% for einkorn wheats and 91% for emmer wheat, respectively.

Analytical Methods

Chemical Composition

Chemical composition of alternative wheats was determined by the Methods of the AACC (1997). Moisture (44-15A), crude fat (30-25) and ash (08-03) were determined on flour samples. Protein content was determined by the Kjeldhal method (46-13). Starch content was determined by the modified procedure of Holm et al. (1986). Total dietary fiber was determined by the Methods of AACC Method 38-11.

Physicochemical Characteristics

SDS sedimentation volumes (AACC 56-61A) and Falling Number (56-81B) of flour samples were determined. Dough properties were determined using the Mixograph (54-40A) and Farinograph (54-21) methods.

Characteristic of Alternative Wheat Starch

1. Starch isolation

Starches were prepared by wet milling, a process in which wheat grains were steeped softened, homogenized and sieved successively using two polypropylene screens, 210 and 70 microns (Abdel-Aal et al. 1997). The isolated crude starches were then purified by suspension in alkaline aqueous solution, then washed thoroughly with water followed by ethanol and acetone and finally dried overnight at 35-40°C. Starch damage and size were determined.

2. Pasting and thermal characteristics

Alternative and check wheat whole meals and starches were compared for swelling power at different temperatures (60, 70, 80 and 90°C) (Figs. 4 and 5, respectively). Swelling power was determined and calculated as described by Sasaki and Matsuki (1998). Pasting properties of starches were measured using a Brabender Viscoamylograph model VA-1A equipped with a 700 cmg cartridge. The stability of alternative wheat starch gels under cold or frozen storage was determined according to the method of Zheng and Sosulski (1998). Thermal characteristics was determined using DSC methodology (Mettler TA 3000, Mettler-Toledo, Inc., Columbus, Ohio) and X-ray diffraction patterns of starches were studied with a Philips Model 42273 diffractometer

(M.B. Philips Corp. Eindhoven, Holland). Starch digestibility was determined by the hydrolyzing of native starch using pancreatic ∀-amylase over a period of time (15-300 min).

Characteristic of Alternative Wheat Proteins

Wheat storage proteins were extracted by two successive extraction methods to recover the two major protein groups, gliadins and glutenins. The first method was the traditional extraction method (Osborne method) using three solvents: 0.5M NaCl, 70% ethanol and 2.0% SDS in 0.5M phosphate buffer. The second method was based on Kruger et al. (1998) using four solvent systems: 0.5M NaCl , 50% 1-propanol, 50% 1-propanol + 4% dithiothreitol (DTT) and 50% 1-propanol + 4% DTT + 1% acetic acid. Also, total storage proteins were extracted with a single extraction method using either 2.0% SDS in 0.5M phosphate buffer or 50% 1-propanol + 4% DTT + 1% acetic acid solvent. Protein in grains and extracts was determined by the Kjeldahl method (N x 5.7). The compositions of gliadins, glutenins and total proteins were studied by acid-polyacrylamide electrophoresis (A-PAGE) and sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) as described by Abdel-Aal et al (1996). The recovery was calculated based on extracted and residual proteins determined by Kjeldahl method.

Gliadin composition of alternative and modern wheats in ethanol and propanol extracts were studied using the Acid-PAGE technique. The SDS-PAGE technique was used to study the composition of SDS in phosphate buffer, propanol-DTT and propanol-DTT-acetic acid solubles or glutenin proteins. Total storage proteins in single-step extracts were analyzed by A-PAGE and SDS-PAGE techniques.

Processing of Alternative Wheats

1. Bread baking

For spelt wheats, the optimized (enriched) straight-dough procedure (AACC 10-10B) was used to evaluate baking quality using the following ingredients: 100g flour, 5.3g active dried yeast, 1.5g salt, 5.0g sugar, 3g shortening, 4g dried skim milk, 02g malt, 40 ppm ascorbic acid and water. Common wheat, Katepwa and commercial flour, Emerald (CSP Food Co.) were used as controls. The ingredients were mixed in a Grain Research Laboratory dough mixer for optimum dough development time of wheat flour and the baking time was 25 min at 230 °C. For Baking quality of Emmer wheat, the basic straight-dough-long fermentation procedure (10-09) was used.

Loaf volume was determined by rapeseed displacement. Crust and crumb color of bread was measured using a HunterLab MiniScan XE. The crust and crumb color of CWRS bread was used as standard to calculate ΔE. The firmness of crumb was measured using a TMS-90 Texture Test System equipped with standard shear compression cell model CS-1.

2. Noodle and Pasta Processing

Noodles

Spelt wheat flour was mixed with a salt solution (1.5% NaCl, 35% absorption) for white-salted noodle. Crumbly dough was passed through roller (No. 1) of ATLAS® Pasta machine (OMC MARCATO, s.r.l., Italy) and rested for 1 hr. The thickness of dough sheet was reduced using progressively smaller gap settings (No. 1, 2, 4 and 6). For convenience of color measurement, the dough sheet was cut into a round shape (3.3 cm dia. x 0.2 cm thickness) and stored in plastic bags for color and texture determination. Noodle strips were prepared from dough sheet using a cutting roller. Color of flour and dough sheet was determined using a HunterLab MiniScan XE, standardized with a white color standard. Texture profile of noodle strips was measured using TMS-90 Texture test System installed with TPA-1 Cell (Food Technology Corp.).

Pasta

Spelt x common wheat lines, which had higher yellowness and texture values, were selected for pasta processing. Pasta was prepared using a small-scale PastaMatic device (SIMAC Appliances Co., New York, NY). Dough was prepared in a separate mixer using an absorption of 38% and shaped using a Tagliatella media disc. Pasta was dried at room temperature for 20-22 hr and stored in plastic bags prior to quality evaluation.

3. Malting Process

Emmer wheats, Emmer19 and Vernal, were steeped and malted in the laboratory using an automatic micromalting system (Phoenix Systems, Kingswood, South Australia). The steeping and germination cycle was 4 - (4) - 4 - (4) - 4 - (4) - 4 - (89) hr; the number outside the parenthesis indicate steep time and those inside, air rest times. The germinated grain was kilned for 10 hr at 49-49°C, 3 hr at 49-54°C, 4 hr at 54-60°C, and 23 hr at 60-85°C. The malted and unmalted grains were ground in a Udy cyclone mill prior to the chemical analysis. Germination energy and germination capacity of grain was determined as described in ASBC (1992). The α-amylase activity and β-glucan were determined with the Megazyme kit (Sydney, Australia) by the method of McCleary and Sheehan (1987) and McCleary and Glennie-Holmes (1985), respectively. Proteolytic activity was determined using the AACC procedure (Method 22-62). Malt extract was prepared as described in ASBC (1992).

4. Cake and Cookie Processing

Einkorn wheat flour was evaluated for cake (10-90) and cookie (10-50D) processing by the AACC Methods (1997). Commercial cake and pastry flour (Robin Hood) was used for comparison purposes.

5. Flaking and Puffing Test

Spelt and puffing wheat flour was flaked using a drum dryer. Puffiness of grain was measured as the rate of expansion using deep-frying instead of a puffing gun. Wheat was tempered to give four levels of moisture (7, 9, 12, 15%) in the grain prior to deep-frying. Also, snacks made from texturized wheat flour were baked or deep-fried to measure the rate of expansion.

6. Sensory Evaluation

Dried noodle was cooked for 6 min in boiling water and rinsed with cold water four times and kept in cold water prior to evaluation. Trained panelists were asked for their preference of noodle brightness, yellowness, surface smoothness, softness and elasticity on a scale of 9 points (1=dislike extremely, 9=like extremely).

Dried pasta was cooked for 20 min (or more) in boiling water until it was fully cooked. Panelists recorded their preference of pasta and macaroni products for firmness, stickiness, color, appearance and flavor on a scale of 4 points (1=very poor, 4=good).

Einkorn cakes were evaluated on a scale of 9 points (1=dislike extremely, 9=like extremely) for overall score. Panelists described the presence of after-taste and recorded acceptability of cakes based on their after-taste.

7. Statistical Analysis

The data were analyzed using Minitab Statistical Software (Minitab Inc. 1998) and the results are presented as means.

RESULTS

A.1. Agronomic Performance of Alternative Wheats

A.1.1 Spelt wheat

In 1998, seven Spelt lines selected from spelt/common wheat crosses were compared to CDC Bavaria and PI348754M spelt as well as Katepwa CWRS wheat. The trial was grown at two sites (Table 1). PI348754M performed better than CDC Bavaria. It was higher yielding, earlier heading, shorter, less lodging prone and had heavier seeds than CDC Bavaria. Like CDC Bavaria, this line is awned. The seven breeding lines were all awnless. Of particular interest is 98SPELT1, which out-yielded CDC Bavaria by 30% and is a semidwarf. 98SPELT5 combined the spelt morphology with increased threshability. We evaluated the baking quality of the check cultivars and four of the seven experimental lines.

Table 1. Agronomic performance of selected Spelt x Common wheat lines in 1998

Cultivar	GY kg/ha	DSE days	DPM days	HT cm	LDG 1 to 9	TWT kg/hL	KWT mg	THR %	Protein %
Katepwa	3748	56.8	85.5	99	1.3	81.0	33.8	95	16.1
CDC Bavaria	3878	64.3	90.8	118	3.0	76.9	40.5	31	14.9
PI348754M	4641	62.8	90.0	113	2.5	76.0	46.5	17	15.4
98Spelt1	5062	61.5	90.5	85	1.3	75.3	42.0	35	16.3
98Spelt2	3821	57.0	86.0	114	1.0	77.6	40.8	29	16.3
98Spelt3	3960	64.0	90.0	118	2.0	77.4	43.3	35	16.0
98Spelt5	3965	61.0	89.0	118	1.5	79.9	45.0	74	15.6
# of sites	2	2	2	2	2	2	2	2	2

DSE = days to spike emergence, DPM = days to physiological maturity, Ht. = plant height, LDG = lodging, T.wt. = test weight, Kwt. = kernel weight, Thresh. = grain threshability.

The first set of 84 awnless spelt lines derived from spring x winter spelt crosses were evaluated in an unreplicated trial format in 1998. Approximately 30 of those lines were advanced for protein-profiling and quality evaluation (Table 2). This first set of breeding material yielded lines that were shorter-strawed with a higher protein content and weaker gluten; all desirable traits.

In addition, a set of 160 spelt/common wheat derivatives (Table 3), were evaluated in unreplicated trials in 1998. Fifty of those lines were advanced for quality evaluation. The best 17 lines were retained for further testing.

Table 2.1998 SpeltxSpelt	Grain yield Average kg/ha	Grain Yield Range	DSE Average days	DSE Range	DPM Average days	DPM Range	Height Average cm	Height Range	Lodge Average 1 to 9	Lodge Range	# of plots
CDC BAVARIA	4877	4627-5389	64.9	64-67	94.2	94-96	120.8	117-124	2.1	1 to 4	7
Breeding Lines	5016	3242-6102	67.3	62-71	95.8	94-97	114.8	93-129	2.2	1 to 5	34

	Grind Time Average sec	Grind Time Range	Protein Average %	Protein Range	SDS Sed. Average cc	SDS Sed. Range	# of plots
CDC BAVARIA	29.6	27-33	15.6	15.1-15.9	55.4	52-58	5
Breeding Lines	29.4	20-58	16.9	15.7-18.4	44.4	36-53	25

Table 3. 1998 Speltxaestivum	Grain yield Average kg/ha	Grain Yield Range	DSE Average days	DSE Range	Height Average cm	Height Range	Lodge Average 1 to 9	Lodge Range	# of plots
CDC BAVARIA	5218	4518-5985	77.1	75-82	124.9	120-131	7.2	6 to 8	13
Breeding Lines	5405	3698-7168	76.9	72-82	122.3	107-134	4.2	2 to 8	89

	Falling no. Average sec	Falling no. Range	Protein Average %	Protein Range	SDS Sed. Average cc	SDS Sed. Range	# of plots
CDC BAVARIA	350.1	322-371	15.3	13.9-15.9	55.3	52-59	10
Breeding Lines	382.7	249-553	15.3	13.7-16.3	40.9	24-56	43

In excess of 1,000 spring x winter spelt derived breeding lines were grown in head rows in 1998. Approximately 400 of those lines were harvested and were subjected to protein fingerprinting and testing for SDS Sedimentation volume. Of those lines, 140 were evaluated in single replicate trial at a single location in 1999 (Table 4). Of those lines, 33 were advanced for further testing in 2000.

In addition, 6,300 spelt/common wheat derivatives were grown in hill plots in 1998. This material was selected for absence of awns, early maturity and spelt spike morphology. Of the lines grown in 1999, approximately 2,600 were grown in rows in 1999.

Table 4. Performance of spring x winter spelt wheat breeding lines grown in 1999

Cultivar	Grain yield Average kg/ha	Grain Yield Range	DSE Average days	DSE Range	Height Average cm	Height Range	Lodge Average 1 to 9	Lodge Range	# of plots
CDC BAVARIA	5218	4518-5985	77.1	75-82	124.9	120-131	7.2	6 to 8	13
Breeding Lines	5405	3698-7168	76.9	72-82	122.3	107-134	4.2	2 to 8	89

	Falling no. Average sec	Falling no. Range	Protein Average %	Protein Range	SDS Sed. Average cc	SDS Sed. Range	# of plots
CDC BAVARIA	350.1	322-371	15.3	13.9-15.9	55.3	52-59	10
Breeding Lines	382.7	249-553	15.3	13.7-16.3	40.9	24-56	43

The first (n = 9) set of awnless spelt lines derived from spring x winter spelt crosses (Table 2)were evaluated in a replicated trial at four sites in 1999. The results are summarized in Table. 5. The data is expressed as a % of CDC Bavaria for yield. The remaining traits are expressed as a deviation from CDC Bavaria. The data is based on the average of the four sites. Lines that were not advanced to the final stage of quality evaluation are not included in the Table, for the sake of brevity.

Table 5. Agronomic performance of selected Spring x Winter spelt lines at four sites in 1999.

	Grain Yield %	DSE days	DPM days	Ht. cm	LDG 1-9	LBL 1-9	T.wt. kg/hL	Kwt. mg	Thresh. %
1 CDC Bavaria	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
2 Katepwa	95	-9.8	-8.9	-24.7	-2.9	5.0	1.9	11.5	53
4 99SPELT2	103	0.9	1.4	1.8	-0.9	-1.0	-5.8	0.4	-20
6 99SPELT4	102	-0.8	1.7	-6.2	-1.2	-1.3	-3.9	0.8	-16
7 99SPELT5	114	-0.9	1.3	0.4	-1.7	-1.0	-4.8	1.2	-14
11 99SPELT9	115	-2.3	-2.9	-5.4	-2.7	-0.7	-1.4	-1.0	0

DSE = days to spike emergence, DPM = days to physiological maturity, Ht. = plant height, LDG = lodging, LBL = leaf blight, T.wt. = test weight, Kwt. = kernel weight, Thresh. = grain threshability.

The most promising line was 99SPELT9. This line was 15% higher yielding than CDC Bavaria and 3 days earlier maturing while maintaining a similar baking quality.

In addition, 17 spelt/common wheat derivatives were evaluated in a replicated trial at three sites in 1999 along with three lines initally tested in 1998 (Table 6).

Table 6. Agronomic performance of spelt x common wheat derivatives in 1999.

	Grain Yield %	DSE d	DPM d	Ht. cm	LDG 1-9	LBL 1-9	T.wt. Kg/hL	Kwt. g	Thresh %
1 Katepwa	86.7	-10.3	-9.0	-26.8	-3.2	5.5	2.8	-7.9	56
2 Bavaria	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
3 98SPELT1	122.6	-4.8	-1.2	-40.3	-4.5	3.5	-3.0	-3.9	7
5 98SPELT5	110.3	-6.3	-3.0	-5.1	-0.2	2.0	1.8	0.6	34
7 99SPELT11	106.3	-10.0	-7.2	-17.8	-0.2	1.0	0.9	-0.7	10
13 99 SPELT17	108.0	-7.7	-5.0	-13.6	0.0	3.0	0.4	0.7	4
14 99SPELT18	107.4	-7.7	-7.5	-12.5	-1.0	3.5	1.0	1.3	12
16 99 SPLT20	108.6	-7.3	-4.5	-9.5	-1.5	1.0	2.4	0.1	12
19 99SPELT23	109.3	-5.0	-4.7	-7.8	-0.2	3.5	-0.6	-6.8	13
22 99 SPELT26	105.2	-8.7	-9.0	-11.8	-1.7	3.0	1.8	-4.4	27

The semidwarf line 98SPELT1 continued to yield very well when re-tested in 1999. The remaining lines were higher yielding than CDC Bavaria with increased grain threshability, earlier maturity and shorter straw. These lines were re-tested in 2000 at two sites.

A number of bulk populations of spelt wheat were also in grown in 2000.

As was the case in 1999, 99SPELT9 was earlier maturing and stronger-strawed than CDC Bavaria (Table 7). The yield of 99SPELT9 was similar to that of CDC Bavaria. In 1999 this line had out-yielded CDC Bavaria by 15%. Thus, averaged over two years, this line yielded 7% higher than CDC Bavaria. A number of lines were higher-yielding than CDC Bavaria and 99SPELT9 in 2000.

The Spring Spelt Private Registration Test was established in 2001 and will be conducted for three years and involves cooperators at AAFC, University of Manitoba and Alberta Agriculture. In 2001 the test contained 11 experimental spring spelt lines, CDC Bavaria and AC Barrie CWRS wheat.

When tested at seven sites in the 2001 Spring Spelt Private Registration Test, 99SPELT9 yielded 14% higher than CDC Bavaria and was earlier maturing and less prone to lodging (Table 7). These results were consistent with those obtained in 1999-2000. Breeder rows of 99SPELT9 were initiated in 2001 in anticipation of a varietal release in 2004.

In addition to the above test, 180 spelt/common wheat derivatives were evaluated in unreplicated trials in 2000. These lines were selected from 2,600 spelt x common wheat derivatives grown in rows in 1999. Of the 180 lines were retained for quality evaluation (Table 8).

Table 7 . Spring spelt wheat lines evaluated in 2000 and 2001

Entry #	Line	2001 Yield kg/ha	2001 % Bavaria	2000 % Bavaria	2001 DSE days	2001 DPM days	2001 Height cm	2001 Lodge 1 to 9	2001 Test wt kg/hL	2001 1000 K wt. grams	2001 Thresh. %
1	AC Barrie	3073	**107.5**	**97.0**	58.9	99.0	85.7	1.5	80.3	33.6	96.0
2	CDC Bavaria	2859	**100.0**	**100.0**	67.8	103.2	106.1	3.3	76.2	36.4	14.4
3	99SPELT9	3254	**113.8**	**100.0**	65.3	102.3	105.3	2.3	75.6	37.4	18.0
4	00SPELT5	3489	**122.0**	**99.6**	66.3	105.0	106.4	3.0	75.2	40.1	12.4
5	00SPELT6	3238	**113.3**	**102.5**	67.3	103.0	102.4	1.8	75.5	39.0	10.4
6	00SPELT8	3365	**117.7**	**105.3**	66.4	104.6	106.4	2.5	76.1	38.5	10.8
7	00SPELT9	3268	**114.3**	**103.5**	64.3	103.7	101.9	1.5	75.0	34.9	7.7
8	00SPELT17	3376	**118.1**	**101.4**	65.4	103.9	105.0	3.0	75.8	39.8	15.7
9	00SPELT20	3375	**118.0**	**104.9**	64.9	103.9	102.3	2.0	75.7	34.5	8.0
10	00SPELT21	3459	**121.0**	**105.8**	67.0	104.4	104.1	2.3	74.5	39.0	10.3
11	00SPELT22	3118	**109.1**	**107.7**	66.6	104.6	106.0	1.8	75.4	40.2	8.7
12	00SPELT25	3506	**122.6**	**115.6**	66.9	104.5	107.6	3.0	75.0	41.9	10.4
13	00SPELT29	3263	**114.1**	**100.5**	62.9	102.0	100.8	2.5	75.6	40.8	6.8
		7	7	4	5	5	6	2	7	7	3

DSE = days to heading; DPM = days to physiological maturity, Lod. = lodging.

Table 8. Evaluation of spelt x common wheat breeding lines in 2000

	Grain yield Average kg/ha	Grain Yield Range	DSE Average days	DSE Range	DPM Average days	DPM Range	Height Average cm	Height Range	# of plots
99SPELT9	5636	5307-5914	69.6	68-71	99.8	98-101	122.4	116-128	27
Breeding Lines	5491	2542-6937	65.7	62-71	99.2	94-106	105.4	86-125	93

	Lodge Average 1 to 9	Lodge Range	Threshab. Average %	Threshab. Range	Protein Average %	Protein Range	# of plots
99SPELT9	3.4	2 to 7	50.4	42.3-55.9	18.3	17.6-19.5	17
Breeding Lines	2.2	1 to 5	79.9	59.1-95.5	16.8	13.6-20.0	36

Eight spelt/common wheat derivatives were grown in a replicated trial at two sites in 2000 (data not presented). The semidwarf line 98SPELT1 continued to yield very well.

A number of bulk populations of spelt wheat were grown in 2000. These populations were subsequently grown in head-rows in 2001 and selections made therefrom.

A second test containing spelt/common wheat derivatives was grown at two sites in 2001 (Table 9).

Table 9. Agronomic performance of selected spelt/common wheat derivatives in 2001.

Entry		Yield kg/ha	Yield % Barrie	DSE days	DPM days	Height cm	Lodge 1 to 9
1	AC Barrie	2789	**100.0**	57.8	89.0	70.0	1.0
2	CDC Bavaria	3252	**116.6**	63.3	92.0	90.3	3.5
3	99SPELT9	3092	**110.9**	61.0	91.0	85.5	2.0
4	2001SPELT1	2483	**89.0**	55.8	84.0	78.0	2.0
5	2001SPELT2	2906	**104.2**	55.3	84.0	83.3	2.5
6	2001SPELT3	2783	**99.8**	56.8	89.3	75.0	2.0
7	2001SPELT4	3206	**115.0**	58.3	90.8	76.3	3.5
8	2001SPELT5	3348	**120.0**	59.0	90.8	76.8	3.0
9	2001SPELT6	3040	**109.0**	57.8	90.8	69.0	3.0
10	2001SPELT7	3385	**121.4**	59.8	90.8	83.3	2.0
11	2001SPELT8	2586	**92.7**	57.5	90.8	69.5	3.0
12	2001SPELT9	3439	**123.3**	57.8	88.8	78.3	3.0
13	2001SPELT10	3148	**112.9**	59.0	91.3	75.5	2.0
14	2001SPELT11	3355	**120.3**	57.5	91.8	73.5	2.5
15	2001SPELT12	3221	**115.5**	57.0	88.3	87.8	2.0
16	2001SPELT13	3390	**121.5**	58.8	89.3	81.8	2.0
17	2001SPELT14	3466	**124.3**	59.8	91.8	83.5	1.0
18	2001SPELT15	3097	**111.0**	58.8	88.8	80.8	1.0
19	2001SPELT16	2905	**104.1**	57.0	86.5	76.8	1.0
20	2001SPELT17	3495	**125.3**	57.3	89.8	87.0	1.5
21	98SPELT1	3222	**115.5**	60.0	91.3	65.3	2.0
22	99SPELT23	3272	**117.3**	59.0	89.0	84.0	3.0
23	99SPELT26	3437	**123.2**	58.0	88.3	84.3	3.0

We planted 570 F4 head rows from 2 new spelt crosses in 2001. A number of bulk populations of spelt wheat are also being in grown in 2001.

A.1.2 Emmer wheat

Seven emmer wheat accessions previously identified as having acceptable baking quality were field-tested at two locations (2 reps/site) in 1998 (Table 10). The lines were compared to Plenty durum and Vernal emmer. The latter has poor baking quality. We advanced four of the PI accessions for more detailed baking evaluation.

Table 10. Agronomic Performance of Selected Emmer Accessions in 1998

Cultivar	GY kg/ha	DSE days	DPM days	HT cm	LDG 1-9	TWT kg/hL	KWT mg	THR %	Protein %
Plenty	4155	57.0	87.5	95	1.0	81.1	44.8	93.0	15.1
Vernal	3995	60.5	87.0	99	5.5	76.7	38.0	30.9	14.1
PI254-171	4045	58.3	85.5	79	8.0	74.0	42.8	28.9	15.6
PI254-176	4152	58.3	85.3	78	6.5	74.7	40.5	40.2	14.9
PI94-663	4216	58.8	86.5	99	9.0	74.2	43.5	34.9	14.1
PI254-164	4202	58.0	86.0	90	7.5	74.5	40.8	38.8	15.5
# of sites	2	2	2	2	1	2	2	2	2

All the emmer wheats we have tested (n=>300) to date were weak-strawed. The vast majority were of a very poor baking quality. We crossed an emmer line with good baking quality with a semidwarf strong gluten durum. Nearly 400 lines were advanced in the greenhouse during the wiinter of 1998/1999 to the F4 generation and were then grown in head-rows in 1999. Another 150 lines were grown in the F3 generation in head-rows.

These 400 F4 lines were screened for threshability and SDS sedimentation volume and the 29 most promising lines were increased in our winter nursery during the winter of 1999/2000. These lines were tested in a replicated trial at three sites in 2000. The objective is to develop a yellow pigmented baking wheat. Eight of the lines were retained for baking tests. These lines were early-maturing and short strawed but lower-yielding than Kyle durum. However, they were similar in yield to WB881 one of the parents in the cross. The main problem with these lines appears to be susceptibility to leaf blight (tan spot and Septoria leaf spot), a trait inherited from the emmer parent (Emmer19). These lines have very high grain protein and SDS sedimentation levels (Table 11).

We have also made one backcross to emmer wheat in order to develop stronger-strawed emmer types. This population was in head-rows in 2001.

Table 11. Emmer/durum baking wheat lines evaluated in 2000 and 2001

	ID	2001 Yield kg/ha	2001 Yield % Kyle	2000 Yield % Kyle	2001 DSE days	2001 DPM days	2001 Height cm	2001 Lodge 1 to 9	2001 Test wt kg/hL	2001 1000 K wt. grams	2001 Thresh. 1 to 10	2000 Protein %	2000 SDS Sed. cc
1	EMMER19	3227	111.0	80.8	58.6	85.5	67.2	3.3	75.2	41.0	7.0	16.4	37.5
2	WB881	2852	98.1	72.0	54.1	87.4	61.2	1.3	80.9	48.4	1.0	15.8	52.8
3	KYLE	2906	100.0	100.0	57.7	88.9	79.7	2.8	81.3	46.9	1.0	15.3	32.0
4	00EB1	2690	92.6	69.6	56.7	86.3	54.7	1.0	77.2	40.2	2.0	17.6	54.9
5	00EB4	2753	94.7	63.9	52.6	83.9	71.6	5.8	79.3	44.0	3.7	17.5	66.7
6	00EB7	2645	91.0	66.7	56.5	85.9	71.9	2.5	76.1	44.3	3.7	16.9	60.5
7	00EB10	2738	94.2	67.1	57.7	86.7	58.9	1.3	76.6	45.8	3.7	16.9	57.2
8	00EB14	2758	94.9	63.0	56.7	88.6	69.6	2.3	78.6	44.2	2.7	16.4	61.0
9	00EB23	2403	82.7	67.2	55.8	85.7	68.4	2.3	75.9	41.1	3.3	17.3	55.8
10	00EB28	2559	88.1	62.8	54.6	86.5	65.9	2.8	76.8	44.2	2.0	15.9	65.3
11	00EB29	2785	95.8	71.8	56.9	87.6	72.7	2.3	78.0	43.1	3.3	15.8	65.5
	# of sites	4		3	4	3	3	2	4	4	4	3	3

In addition to the above lines, 200 lines reselected from 1999 head-rows were grown in rows in 2000. This material was screened for SDS sedimentation volume and 90 lines were subsequently tested in unreplicated trials in 2001 (Table 12).

Table 12. Evaluation of emmer/durum derivatives in 2000-2001.

	2001 Grain yield Average % WB881	2001 Grain yield # of plots	2001 Grain yield Range % WB881	2000 SDS Sed Average cc	2000 SDS Sed # of rows	2000 SDS Sed Range cc
WB881	100.0	9	91.0-115.7	54.5	2	53-56
Kyle	102.8	6	85.2-113.5	34.0	1	
Breeding Lines	82.5	93	49.9-114.8	61.5	105	33-81

Over 600 new emmer/durum derivatives were evaluated in head rows in 2001.

A.1.3 Einkorn wheat

Partial-threshing lines of einkorn wheat were evaluated at two sites (2 reps/site) in 1998 (Table 13). Of the 34 lines, 8-10 deserved further evaluation based on their higher threshability scores compared to the parental line (Treatment 2). The hulled check (TM23) continues to yield 25% (groat basis) higher than the soft-glumed material. We crossed TM23 with one of the high-threshing lines in order to increase the yield-potential of this material.

Table 13. Agronomic performance of threshable einkorn wheat lines in 1998

Entry	ID	Yield	Yield	DSE	DPM	Height	Lodge	Test wt	1000 K wt.	Thresh.
		kg/ha	%Uno	days	days	cm	1 to 9	kg/hL	grams	%
1	TM23	4092	**150.3**	60.9	92.5	94.0	7.0	78.6	32.0	16
2	UNO	2723	**100.0**	60.5	92.4	99.0	4.8	76.6	39.5	66
3	98EINK1	2876	**105.6**	61.1	92.1	101.0	3.4	77.4	37.0	78
5	98EINK3	2609	**95.8**	61.8	93.9	100.0	5.6	75.3	34.5	80
6	98EINK4	2701	**99.2**	61.8	92.9	102.0	3.0	77.7	34.0	73
7	98EINK5	2831	**104.0**	60.4	91.5	99.0	3.3	77.7	37.3	65
8	98EINK6	2774	**101.9**	60.6	92.3	101.0	4.1	78.0	40.5	82
10	98EINK8	2668	**98.0**	61.7	93.1	103.0	2.2	77.5	38.3	77
11	98EINK9	2782	**102.2**	60.7	92.7	96.0	1.9	78.5	36.3	81
12	98EINK10	2669	**98.0**	63.2	92.7	104.0	4.8	77.2	38.3	85
13	98EINK11	2792	**102.5**	59.1	92.3	106.0	3.3	75.4	35.3	79
17	98EINK15	2913	**107.0**	62.1	92.2	104.0	6.6	76.9	37.5	81
18	98EINK16	2607	**95.7**	62.4	93.2	103.0	5.1	76.6	37.5	78
21	98EINK19	2613	**96.0**	60.6	93.2	102.0	4.0	77.0	38.8	85
22	98EINK20	2652	**97.4**	61.0	92.5	102.0	3.2	77.3	36.3	75
33	98EINK31	2815	**103.4**	60.7	91.6	100.0	4.4	77.7	37.0	82
34	98EINK32	2879	**105.7**	60.9	92.0	97.0	2.8	78.0	36.3	81
35	98EINK33	2793	**102.6**	61.3	92.0	104.0	4.8	76.8	37.8	79
36	98EINK34	2777	**102.0**	59.9	92.4	98.0	2.2	78.5	35.0	79
		2		2	2	2	2	2	2	2

Of 34 partial-threshing einkorn lines first tested in 1998, eight were re-evaluated in a replicated trial at four sites in 1999 (Table 14).

Table 14. Agronomic performance of selected partial-threshing lines einkorn wheat lines in 1999.

		Grain Yield %	DSE d	DPM d	Ht. cm	LDG 1-9	LBL 1-9	T.wt. g/hL	Kwt. g	Thresh. %
1	TM23	145.7	3.2	1.7	0.3	0.22	-3.0	3.3	-5.7	-52
2	Uno	100.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
3	98EINK1	109.3	0.2	-0.3	7.7	-0.35	-1.6	1.6	-4.4	6
4	98EINK6	98.1	0.2	-1.1	1.0	-0.45	1.4	3.0	-2.9	1
8	98EINK15	103.1	1.8	-0.3	6.2	0.60	1.0	0.5	-3.8	2
9	98EINK31	97.4	-0.2	0.0	4.2	1.20	-0.3	1.5	-5.5	-4
10	98EINK32	104.3	-0.2	-1.3	-1.3	-1.06	-0.6	1.4	-4.8	7

The partially-threshing lines continued to yield 25% less on a net basis (after accounting for hull weight in TM23) than the hulled control (TM23). 98EINK1, 98EINK31 and 98EINK32 had the best quality and were advanced for further testing in 2000.

A number of lines from a cross between TM23 (hulled einkorn) and a high-threshing line were advanced to the F3 generation in the greenhouse and tested for threshability. This

material was grown in head rows in 1999. These lines were retested for threshability and the best 25 lines were increased in our winter nursery. These lines were tested at two sites in 2000.

We made a further backcross of the threshability gene to TM23 in order to increase the yield potential of the threshable einkorns.

Einkorn wheats were grown in a replicated trial at two sites in 2000 and four sites in 2001 (Table 15). A 7-entry test of spring einkorn wheats was sown at four sites in 2001. These lines had superior cake baking quality and generally lacked the undesirable after-taste detected in some lines. The partially-threshing control (Uno) continued to yield 25% less on a net basis than the hulled control (TM23). 98EINK31, another partially-threshing line was identified as having good quality based on data collected in early 2000. The lines tested for the first time in 2000 (00 series) ranged in threshability. The most threshable lines were lower yielding than Uno and were discarded. A number of hulled lines were retained as they were higher-yielding than TM23 (Table 15).

Table 15. Agronomic performance of selected einkorn wheat breeding lines in 2000 and 2001

Entry	ID	2001 Yield	2001 Yield	2000 Yield	2001 DSE	2001 DPM	2001 Height	2001 Lodge	2001 Test wt	2001 1000 K wt.	2001 Thresh.
		kg/ha	% Uno	% Uno	days	days	cm	1 to 9	kg/hL	grams	1 to 10
1	TM23	2433	**154.8**	**140.7**	59.1	90.7	71.4	4.3	30.6	79.1	7.8
2	UNO	1572	**100.0**	**100.0**	58.9	90.8	74.4	2.0	36.4	77.1	2.3
3	98EINK31	1590	**101.1**	**70.0**	58.3	91.3	76.7	3.0	32.3	78.3	2.8
4	00EINK1	2659	**169.1**	**160.1**	59.2	90.7	72.8	5.0	28.1	80.0	7.0
5	00EINK3	2620	**166.7**	**145.5**	59.0	90.3	71.4	4.0	28.1	79.7	6.8
6	00EINK11	2489	**158.3**	**155.5**	59.1	90.6	73.7	7.3	28.1	80.4	7.0
7	00EINK22	2515	**160.0**	**149.8**	58.3	89.6	71.3	8.0	30.2	79.6	7.0
	# of sites	4		2	4	4	3	1	C	C	4

Approximately 100 lines were head-rowed in hills in 2000. Those lines were assessed for threshability and re-tested in rows in 2001. Single plant selections were made from a BC1F4 population (TM23*2/Uno). This material was head-rowed in 2001. Our objective is identify higher-yielding partially-threshable einkorn lines. Over 700 head rows of partially-threshing Einkorn were sown in 2001 and selected for threshability. This material would be available for yield-testing in 2002.

A.1.4 Puffing wheats

We increased the seed of 20 large-seeded lines derived by T. turanicum x T. durum crosses in our 1998/1999 winter nursery. These lines were subsequently evaluated in a replicated trial at two sites in 1999 (Table 16). Three of the lines were re-tested in 2000 (Table 17). The lines were 16 to 20 mg heavier than Kyle durum in single kernel weight

and the kernels were 2 mm longer than in Kyle CWAD wheat. These initial lines were lower yielding due to poorer leaf spot reaction.

Table 16. Evaluation of puffing wheat lines in 1999.

Entry	ID	Yield kg/ha	Yield %PI211	DSE days	DPM days	Height cm	Lodge 1 to 9	Leaf blight 1 to 9	Test wt kg/hL	1000 K wt. grams
1	Kyle	4802	113.3	64.3	104.0	104.8	3.3	2.0	81.1	46.8
2	PI211691	4240	100.0	63.8	104.8	109.0	3.5	4.0	77.6	71.9
3	99PUFF1	3429	80.9	61.0	109.3	69.3	1.3	7.0	75.5	64.1
4	99PUFF2	3579	84.4	61.8	110.3	70.5	1.0	7.5		
5	99PUFF3	4018	94.8	61.5	108.5	70.5	1.8	7.0		
6	99PUFF4	3860	91.0	63.8	109.5	64.0	1.0	7.0		
7	99PUFF5	3404	80.3	63.3	108.8	70.5	1.0	7.0		
8	99PUFF6	3392	80.0	63.0	110.5	68.3	1.8	7.5		
9	99PUFF7	4235	99.9	63.8	102.8	106.0	2.5	6.0	79.0	61.9
10	99PUFF8	4435	104.6	63.0	103.8	108.5	3.8	3.0	79.5	62.7
11	99PUFF9	3852	90.8	63.0	107.3	101.8	3.3	5.0	77.2	71.4
12	99PUFF10	4347	102.5	59.8	100.8	100.5	3.0	6.0		
13	99PUFF11	3692	87.1	62.9	109.3	83.3	2.0	4.5	75.9	67.1
14	99PUFF12	3921	92.5	64.0	105.5	106.0	2.8	3.0	77.4	62.3
15	99PUFF13	4057	95.7	65.0	106.3	105.0	2.5	2.5		
16	99PUFF14	3740	88.2	60.8	108.0	76.3	1.5	6.5		
17	99PUFF15	3686	86.9	60.0	109.3	72.5	1.0	6.0		
18	99PUFF16	3711	87.5	59.3	107.3	72.3	1.0	7.0		
19	99PUFF17	3765	88.8	60.8	109.3	71.8	1.0	6.5		
20	99PUFF18	3323	78.4	60.0	109.5	68.0	2.0	7.5		
21	99PUFF19	3441	81.2	63.3	109.5	68.5	1.3	7.5		
22	99PUFF20	3613	85.2	64.3	110.5	70.5	1.3	6.5		
	# of sites	2		2	2	2	1	1	2	2

Entry number 2 (PI211691) is the Triticum turanicum (Khorasan wheat) control.

Of the 150 lines evaluated in single replicate trials at one site in 1999, 11 were tested in 2000 at three sites in a replicated trial. Of 1,200 F4 lines in 1999, 80 were re-tested in single-rep trials in 2000. We are attempting to develop large-seeded lines with a rice-shaped kernel. This material was grown for two generations in the greenhouse and was subsequently grown in F5 head-rows in the field in 2000. Crosses between the first cycle of puffing wheats and durum were made in order to improve the leaf disease resistance of this material.

Of the lines evaluated in the replicated trial at three sites in 2000, only three were retained for quality evaluation. As was the case in 1999 these initial lines were lower yielding due to poor leaf spot resistance. The seed size difference between the Khorasan wheat parent (PI211691) and Kyle was 18 mg/seed in 2000. This was down from the typical 22-25 mg differential. Although the breeding lines had longer kernels they were lighter than in 1999 (Table 17).

In addition to the lines in Table 17, 80 lines were yield-tested in un-replicated trials at Saskatoon in 2000 Of those lines, 25 were evaluated for seed weight and length. The best lines were yield-tested in 2001.

In excess of 2,500 puffing wheat experimental lines were grown in head-rows in 2000. Approximately 30% of those lines were harvested. This material was be screened for seed size. These experimental lines were from nine populations in which we were attempting to develop large-seeded lines with a rice-shaped kernel.

Table 17. Puffing wheat lines evaluated in 2000

	Grain yield kg/ha	DSE d	DPM d	Height cm	Lod. 1-9	TWT kg/hL	1000K g
1 Kyle	4699	59.2	99.2	105.8	3.0	81.1	50.1
2 211691	3462	60.0	101.2	107.0	4.2	77.4	68.0
3 99PUFF1	2994	58.7	102.5	70.2	1.7	72.8	51.2
4 99PUFF8	4106	59.5	102.7	107.8	4.7	79.4	58.8
16 00PUFF11	3773	60.2	105.2	73.8	1.7	75.3	58.5

In excess of 180 lines selected for flatter, longer seed shape were being grown in unreplicated trials in 2001. Of the 180 lines, half were discarded due to low yield prior to measuring seed weights (Table 18) Approximately 20 of those lines were long-seeded with high seed weight. These 20 lines could be yield-tested in 2002. An additional group of 900 lines was grown in head rows and screened for seed weight.

Table 18. Evaluation of rice-shaped puffing wheats in 2001.

	2001 1000 K.wt. Average grams	2001 1000 K.wt. Range	2001 1000 K.wt. # of plots	2001 Seed length 20 seeds (cm) Average	2001 Seed length 20 seeds (cm) Range	2001 Seed length # of rows
PI211691	65.3	59.3-70.8	16	20.2	19.6-20.9	16
Kyle	44.3	41.2-46.2	5	15.9	15.5-16.4	5
Breeding lines	55.8	37.6-75.0	92	18.8	17.0-20.2	43

A.2. Characteristic of Alternative Wheat Starches

Einkorn, a high protein wheat, contained the lowest level of starch (61.8%) among alternative wheats (Table 19). This level was similar to that in the wheat checks. The other alternative wheats had relatively higher starch concentrations, ranging from 64.7 to 68.1%. Amylose content was similar in alternative and common wheat, but was lower in durum.

Table 19. Starch and Amylose Contents of Alternative Wheat Grains and their Starch Isolate Yields and Extraction Efficiencies in Comparison with Durum and Common Wheat (dry basis)

Starch source	Starch (%)	Amylose (% of starch)	Starch yield (g/100g grain)	Starch extraction efficiency (%)	
				Crude[a]	Pure[b]
Alternative wheats					
Einkorn	61.8	27.1	46.8	75.7	65.9
Emmer	64.7	27.7	63.6	98.3	84.7
Khorasan	67.1	27.5	61.9	92.3	80.3
Hard spelt	65.7	28.5	56.1	85.4	74.8
Soft spelt	68.1	26.8	60.2	88.4	76.9
Wheat checks					
Durum	62.6	21.4	61.7	98.5	86.1
Common	61.1	28.8	58.1	95.1	82.8

[a](g crude starch isolate/g starch in grain) x 100.
[b](g starch in isolate/g starch in grain) x 100.

Table 20. Damaged Starch contents of Alternative Wheat Wholemeals and Starches in Comparison with Durum and Common Wheat (%dry basis)

Starch source	Wholemeal	Starch isolate
Alternative wheats		
Einkorn	1.04	0.37
Emmer	5.54	0.54
Khorasan	6.22	0.71
Hard spelt	2.53	0.39
Soft spelt	2.05	0.51
Wheat checks		
Durum	5.88	0.56
Common	4.03	0.43

A.2.1. Starch Isolation, Yield, Granule Size and Composition

Yield and extraction efficiency of starches isolated from alternative and check wheats are reported in Table 19. Einkorn yielded the lowest starch having low starch extraction efficiency either calculated based on crude or pure starch. Emmer and durum wheats had exceptionally high starch extraction efficiencies compared to other wheats. Isolation of starch form intact wheat grains resulted in lower starch damage compared to starch damage percent in wheat wholemeals (Table 20). Emmer, Khorasan and durum as very hard wheats had high levels of starch damage due to the grinding process, while einkorn as a very soft wheat exhibited the lowest level of starch damage. Isolated starches showed a similar trend to the wholemeals.

It is well known that wheat, barley and rye starches contain two types of starch granules; type A-granule or larger granule (>10μm) and type B-granule or small granule (1-10μm). Alternative wheat starches showed no exception having the two types of granules (Fig. 1) which were similar to wheat controls (Fig 2). Data in Table 21 showed average granule diameter and percent of type A and type B starch granules as measured by Image Analyzer. The bi-model starch character of alternative and check wheats is evidenced by scanning electron microscope-photomicrographs (Fig. 3).

The chemical composition of alternative and check wheat isolated starches is presented in Table 22. Starch content in all isolated starches was similar, averaging 94%. Corn starch from Sigma chemical Company was included for comparison purposes. Corn starch contained 94.8% starch. Amylose content was higher in wheat starches than in corn starch, but einkorn and soft spelt starches exhibited lower amylose than other alternative and check wheat starches. Protein, hexane-extractable fat and ash contents were similar in alternative and check wheat starches as well as corn starch.

A.2.2. Pasting and Thermal Characteristics

Alternative and check wheat wholemeals and starches were compared for swelling power at different temperatures (60, 70, 80 and 90°C) (Figs. 4 and 5, respectively). Swelling power is a simple test and was recently recognized as an indicator of noodle quality (Sasaki and Matsuki 1998). The swelling power of wholemeals and isolated starches behaved differently as the temperature was increased. Wholemeal swelling power increased with increasing temperature from 60 to 80°C, then declined at 90°C, while swelling power of isolated starches continued to increase until 90°C. In addition, the range of swelling power of isolated starches was higher than that of wholemeals. Above the gelatinization temperature (70°C and up), check wheat wholemeals or starches had a higher swelling power than those of alternative wheats.

Wheat starch, as a major component, could affect texture and viscosity of end-use products. There was a wide variation among alternative wheat starches in their pasting properties (Table 23). Peak viscosity of alternative wheat starches was markedly different, with einkorn starch having the highest peak viscosity (Fig. 6) Khorasan wheat starch showed pasting properties similar to those of durum starch (Fig. 7), while CDC

Table 21. Average Diameter and Percent of type A and type B Starch Granule of Alternative and Modern Wheats

Starch source	Diameter (μm)	Type A (%)	Type B (%)
Alternative wheats			
Einkorn	7.5 ± 5.2	71.6	28.4
Emmer	7.4 6.1	78.4	21.6
Khorasan	9.5 8.2	72	28
Hard spelt	7.7 5.8	80	20
Soft spelt	8.4 6.8	76.4	23.6
Wheat checks			
Durum	8.8 8.3	76.9	23.1
Common	8.3 6.2	71.4	28.6

Table 22. Chemical composition of Alternative Wheat Starches in Comparison with Durum, Wheat and Corn Starches (dry basis)

Starch source	Starch (%)	Amylose (% of starch)	Protein (%)	Fat (%)	Ash (%)
Alternative wheats					
Einkorn	94.1	22.8	0.34	0.04	0.1
Emmer	93.2	26.7	0.23	0.02	0.07
Khorasan	93.1	28	0.28	0.03	0.1
Hard spelt	95.3	27.4	0.25	0.07	0.07
Soft spelt	93.5	23.2	0.28	0.01	0.08
Controls					
Durum	93.6	24.9	0.21	0.02	0.08
Common wheat	94.5	28.3	0.21	0.02	0.11
Corn	94.8	21	0.32	0.01	0.08

Table 23. Pasting Properties of Alternative Wheat Starches in Comparison with Durum, Wheat and Corn Starches

Starch source	Pasting Temperature (°C)	Peak Viscosity[1] (BU)	Viscosity at 95°C (BU)	Viscosity after 30 min at 95°C (BU)	Viscosity at 50°C (BU)	Set-back on cooling (BU)	Viscosity after 30 min at 50°C (BU)
Alternative wheats							
Einkorn	85	540	520	500	1130	630	1070
Emmer	85	230	220	240	640	400	615
Khorasan	84	420	410	460	1060	600	1030
Hard spelt	87	180	160	160	450	290	400
Soft spelt	84	270	250	280	730	450	710
Controls							
Durum	84	400	380	440	1020	580	985
Common wheat	84	280	260	280	750	470	730
Corn	75	500	460	390	860	470	800

Bavaria soft spelt starch exhibited similar pasting properties to those of CWRS wheat starch (Fig.8). Hard spelt starch showed lower pasting properties compared to soft spelt and CWRS wheat starches (Fig. 8). The stability of alternative wheat starch gels under cold or frozen storage was determined according to the method of Zheng and Sosulski (1998). There were also marked differences in net syneresis of alternative and check wheat starch gels, particularly under cold storage (Table 24). Generally, wheat starch gels were more stable than corn starch gel when stored at 4 °C or -15°C. Einkorn starch gel was more stable either under cold or frozen storage for the test period (7 days). No water was released (% expelled water = 0.0) from einkorn starch gels due to storage for one week at 4°C or -15°C.

The DSC characteristics of alternative and check wheat starches and corn starch are reported in Table 25. Three transition temperatures were measured, e.g. onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c) in addition to enthalpy or heat of gelatinization. T_o ranged from 51.1 to 53.4 °C in alternative wheat starches compared to 52.3 to 53.0 °C in check wheat starches and 57.1 in corn starch. T_p was similar in alternative wheat starches averaging 61.3 °C compared to 60.9, 62.1 and 70.0 °C for durum, CWRS wheat and corn starch, respectively. T_c ranged from 69.3 to 73.9 °C in wheat starches compared to 80.5 °C for corn starch. Spelt wheat starches had a wider range of transition temperatures compared to other starches, but were still lower than for corn starch. Khorasan wheat starch had an enthalpy of gelatinization (ΔH) similar to that of durum wheat starch, being the lowest. Spelt and einkorn starches were similar to CWRS wheat starch in ΔH.

A.2.3. Structure and Digestibility

The X-ray diffraction patterns and percent relative intensity of major peaks in the diffractograms of alternative and check wheat starches are presented in Fig. 9 and Table 26, respectively. All alternative wheat starches showed major peaks near d-spacings of 5.8, 5.2, 4.9 and 3.8 Δ which are characteristics of an X-ray A-type starch crystal. However, significant variation in the degree of crystallinity was observed. Einkorn and hard spelt starches had a lower percent of relative intensity indicating a lesser degree of crystallinity. Emmer and Khorasan were similar to durum, while soft spelt was comparable to CWRS wheat.

Native ungelatinized starches isolated from alternative and check wheats were hydrolyzed by pancreatic α-amylase over a period of time (15-300 min). The relationship between incubation time and concentration of released maltose as an indicator of starch hydrolysis was plotted (Fig. 10). The in *vitro* starch digestibility rate (mg released maltose/g starch/hr) was calculated (Table 27). As expected, the degree of starch digestibility increased as the incubation time was increased, but at different rates for each wheat starch. CWRS wheat starch exhibited the lowest rate of digestibility followed by soft spelt and emmer wheat starches. On the other hand, einkorn starch had the highest rate of digestibility.

Table 24. Free Water of Freshly Cooked Pastes and Syneresis of Expelled and Absorbed Water from Alternative and Check Wheat and Corn Starch Gels after One Week of Cold and Frozen Storage (% gel wt)

Starch source	Free water	Expelled water	Absorbed water	Net syneresis
	After 7-days storage at 4°C			
Einkorn	2.6	0	3.14	0.53
Emmer	2.68	2.94	3.92	4.18
Khorasan	2.68	4.9	3.71	5.94
Hard spelt	2.83	0.63	4.38	2.18
Soft spelt	2.72	5.47	4.37	7.12
Durum	3.01	2.43	3.89	3.31
Common wheat	2.85	4.62	4.04	5.8
Corn	3.47	6.26	12.81	15.6
	After 7-days storage at −15 °C			
Einkorn	2.6	0	45.54	42.93
Emmer	2.68	2.67	53.21	53.2
Khorasan	2.67	1.69	53.25	52.27
Hard spelt	2.83	4.92	56.17	58.27
Soft spelt	2.72	2.81	56.16	56.24
Durum	3.01	1.97	52.77	51.73
Common wheat	2.85	2.96	54.83	54.94
Corn	3.47	4.01	57.5	58.04

Table 25. DSC Characteristics of Alternative Wheat Starches in Comparison with Durum, Wheat and Corn Starches

Starch source	Endothermic transition temperature (°C)				Enthalpy of gelatinization (ΔH, J/g)
	Onset (T_o)	Peak (T_p)	Conclusion (T_c)	Range (°C) ($T_c - T_o$)	
Alternative wheats					
Einkorn	53.4	61.3	71	17.6	11.1
Emmer	52.6	61	69.9	17.3	10.5
Khorasan	51.1	60.7	69.6	18.5	9.2
Hard spelt	52.3	61.8	73.9	21.6	11
Soft spelt	50.7	61.9	71.1	20.4	10.7
Controls					
Durum	52.3	60.9	71	18.7	9.2
Common wheat	53	92.1	71.5	18.5	11.2
Corn	57.1	70	80.5	23.4	12.7

Table 26. Percent Relative Intensity[a] of Major Peaks in the X-ray Diffraction Patterns of Alternative Wheat Starches in Comparison with Durum and Wheat Starches

Starch sample	X-ray diffraction angle (2θ)			
	15.2 (5.8)[b]	17.2 (5.2)	18.0 (4.9)	23.2 (3.8)
Alternative wheats				
Einkorn	18.6	22.3	23	23.8
Emmer	22.2	25.8	26.2	26.2
Khorasan	23.3	28.7	28.7	28.3
Hard spelt	17.8	22.3	22.9	22
Soft spelt	26.4	33	32.5	32.5
Wheat checks				
Durum	22.8	28	27.6	26.7
Common	28.7	34.6	34.6	33.2

[a]Starch peak intensity/standard peak intensity (alumina) x 100.
[b]Numbers in parentheses are starch crystal d-spacing (Δ).

Table 27. *In-Vitro* Digestibility rates of Alternative Wheat Starches in Comparison with Durum, Wheat and Corn Starches

Starch source	Digestibility rate (calculated as the slope of first order equation) (mg released maltose/g starch/hr)
Alternative wheats	
Einkorn	109.63
Emmer	94.89
Khorasan	108.17
Hard spelt	101.32
Soft spelt	93.93
Controls	
Durum	104.06
Common wheat	88.71
Corn	100.55

A.3. Characteristic of Alternative Wheat Proteins

Alternative wheats including, TM23 einkorn (diploid wheat), Vernal emmer and Dragon Khorasan (teraploid wheats), PGR8801 hard spelt and CDC Bavaria soft spelt (hexaploid wheats) were evaluated for protein composition as they relate to their end-uses. Kyle durum and Katepwa CWRS wheat were included as conventional wheat checks.

A.3.1. Protein Contents of Grains and Extracts

Protein content varied among alternative and modern wheats depending on wheat type and class (Table 28). Einkorn and hard spelt had relatively higher levels of protein compared to other alternative wheats and durum and bread wheat. Alternative wheat grains greatly exceeded Soft White wheat grains in protein content by about 5 to 8 % units.

Storage proteins in alternative and modern wheat grains were successively extracted by two solvent systems. The traditional fractionation method of Osborne using 05M NaCl, 70% ethanol and 2.0% SDS in 0.05M phosphate buffer (Table 28) was compared with Kruger et al. (1998) method using 05M NaCl, 50% 1-propanol, 50% 1-propanol + 4% dithiothreitol (DTT) and 50% 1-propanol + 4% DTT + 1% acetic acid (Table 29). Also, total storage proteins were extracted by a single-step extraction using either 2.0% SDS in 0.5M phosphate buffer or 50% 1-propanol + 4% DTT + 1% acetic acid (Table 30). Propanol (50%) was found to extract a higher amount of gliadin proteins compared to ethanol (70%), i.e. 32-42% of total proteins (Table 29) vs 24-36% (Table 28). SDS in phosphate buffer extracted lower amount of glutenins compared with propanol-DTT solvent. With the Kruger et al. (1998) method, the remaining of glutenin proteins were further extracted with propanol-DTT-acetic acid solvent which solubilized only a small amount (1.6-5.3%) of glutenins (Table 29).

Among alternative wheats, emmer had the lowest level of glutenins (LMW- and HMW-Gs), while einkorn contained the lowest percent of remaining glutenins (Table 29). Khorasan was similar to durum in the extractable amount of LMW- and HMW-Gs, while spelts had a slightly higher content of LMW- and HMW-Gs compared to common wheat. Alternative wheat storage proteins were slightly more extractable compared with wheat checks in the single-step extraction procedure either with SDS in phosphate buffer or 1-propanol-DTT-acetic acid (Table 30). Using the single-step extraction procedure, SDS in phosphate buffer was found to extract more proteins compared to the propanol-DTT-acetic acid solvent system. Protein recoveries, however, were similar in alternative and modern wheats. The recovery was calculated based on extracted and residual proteins determined by the Kjeldahl method.

A.3.2. Gliadin Composition

Gliadin composition of alternative and modern wheats in ethanol and propanol extracts were studied using A-PAGE technique (Fig. 11). Gliadin proteins differed among wheat grains. Einkorn, emmer and Khorasan wheats were characterized by the absence of most

Table 28. Protein Percent of Alternative Wheat Grains and Sequential Extracts Obtained by Osborne Procedure in Comparison with Durum, Soft and Common Wheats (% of total proteins)

Wheat grain	Protein in grain (%)	0.5M NaCl extract (albumins & globulins)	70% ethanol extract (gliadins)	2.0% SDS[a] extract (glutenins)	Residual proteins	Recovery (%)
Alternative wheats						
Einkorn	20.5	28	23.9	18	30	102.9
Emmer	16.6	31.3	35.7	16.1	16.7	102.5
Khorasan	16.5	27	32.9	13.9	26	102.7
Hard spelt	19.4	27.5	28.4	9.4	34.6	102
Soft spelt	17.4	27.1	24.1	8.5	40.2	104.1
Wheat checks						
Durum	17.2	28	28.3	10.9	32.7	102.4
Soft	11.9	37.4	26.7	12.5	23.7	105
Common	17	29.3	27.9	9.3	33.3	104.7

[a]Sodium dodecyl sulfate.

Table 29. Protein Percent of Alternative Wheat Sequential Extracts Obtained by Kruger et al. Procedure in comparison with Durum, Soft and Common Wheats (% of total proteins)

Wheat grain	0.5M NaCl extract (albumins & globulins)	50% propanol extract (gliadins)	50% propanol+4% DTT[a] extract (LMW+HMW glutenins)	50% propanol+4% DTT[a] +1% acetic acid extract Remaining LMW + HMW glutenins)	Residual proteins	Recovery (%)
Alternative wheats						
Einkorn	27.6	34.7	25.1	1.6	11	99.8
Emmer	29.2	42.2	13.3	4.1	10.9	104.9
Khorasan	26.4	38.1	17.9	5	12.1	103.4
Hard spelt	24.9	32.8	23.8	3.8	11.9	104.6
Soft spelt	24.1	35.5	23.9	5	11.4	105.7
Wheat checks						
Durum	24.7	40.3	18.5	5.3	12.4	105.1
Soft	33.3	34.1	13.5	3.6	15.4	104.6
Common	25.9	32.1	19.8	5.4	14	105.5

[a]Dithiothreitol.

Table 30. Percent of Total Protein in Alternative Wheat Extracts Obtained by a Single-Step Extraction Compared with Durum, Soft and Common Wheats (% of total proteins)

Wheat grain	2.0% SDS[a] extract			50% propanol+4% DTT[b] +1% acetic acid extract		
	Extracted	Residue	Recovery	Extracted	Residue	Recovery
Alternative wheats						
Einkorn	93.9	6.1	101.3	74.4	25.6	98.5
Emmer	93.9	6.1	96.7	75.1	24.9	104.7
Khorasan	88.8	11.2	94.4	72.3	27.7	102.3
Hard spelt	90.4	9.6	97.3	74.7	25.3	98.1
Soft spelt	87.5	12.5	98.8	76.5	23.5	103.7
Wheat checks						
Durum	96.2	13.8	96	69.2	30.8	99.1
Soft	89.6	10.4	98.9	69.1	30.9	103.6
Common	84.4	15.6	99.2	72.9	27.1	105

[a]Sodium dodecyl sulfate.
[b]Dithiothreitol.

ω- and γ- gliadins as did durum. The gliadin composition of Khorasan wheat was almost identical to that of durum. Hard and soft spelts contained several ω-gliadin bands similar to CWRS wheat, but the latter had a slow-moving ω-gliadin band which was absent in spelt wheats. Soft White wheat was found to contain only two bands in the ω-gliadin region. There were no differences in gliadin proteins extracted by either 70% ethanol or 50% propanol. When ethanol and propanol solubles were analyzed by SDS-PAGE technique (Fig. 12) there were small amounts of HMW polypeptides (.97 KD) as contaminants. This indicates some overlap between gliadin and glutenin proteins. The MW of these glutenin subunits (bands) were dissimilar among wheat species. The ω-gliadin proteins differed among wheat species, but Khorasan was similar to durum; soft spelt contained one more band compared to common wheat.

A.3.3. Glutenin Composition

The SDS-PAGE technique was used to study the composition of SDS in phosphate buffer, propanol-DTT and propanol-DTT-acetic acid solubles or glutenin proteins (Figs 13 and 14). Again HMW glutenin subunits varied among wheat species and classes. Einkorn had two major HMW bands similar to soft wheat, but the latter contained one more HMW glutenin subunit. There was a slight variation between Khorasan and durum in HMW glutenin subunits. The HMW glutenin composition of hard spelt was different from that of soft spelt, reflecting dissimilar characteristics and end-uses. The composition of HMW glutenins in soft spelt was somewhat similar to common wheat indicating potential in breadmaking.

A.3.4. Total Storage Protein Composition

Total storage proteins in single-step extracts were analyzed by A-PAGE and SDS-PAGE (Fig 15 and 16, respectively). SDS in phosphate buffer and propanol-DTT-acetic acid were used to extract wheat storage proteins. SDS extract was only analyzed by SDS-PAGE, while propanol-DTT- acetic acid was analyzed by the two techniques. Both techniques showed variations in protein composition among wheat species, but SDS-PAGE provides specific information concerning each protein group, e.g. HMW glutenin subunits, ω-gliadin, LMW glutenin subunits and α-, β- and γ-gliadins. The same findings mentioned above can also be obtained from analyzing total storage proteins in propanol-DTT-acetic acid by SDS-PAGE, particularly for HMW glutenin subunits and ω-gliadins.

A.4. Utilization and Quality Evaluation of Alternative Wheats

A.4.1. Baking and noodle quality of Spelt wheat

A.4.1.1. Bread Baking

Physicochemical characteristics of wheat grain and chemical composition of Spelt wheat flour are presented in Tables 31 and 32. Common wheat cv. Katepwa was used for comparison purposes. Spelt wheat had a similar chemical composition to Katepwa except for a shorter time for dough development and stability in Farinograph tests.

Table 31. Physicochemical Characteristics of Wheat Grain from Spelt and Common Wheat

Wheat samples[1]	Protein (%)	SDS-sedimentation	Falling number
CDC Bavaria	16.83	47.50	302.5
99Spelt4	16.68	34.25	138.0
99Spelt5	17.97	35.25	321.5
99Spelt9	16.38	44.25	280.0
Common wheat			
Katepwa	16.91	54.75	417.5

[1] 1999 Crop composite from S. F. (early and late) and Kernen.

Table 32. Chemical Composition and Farinograph Characteristics of Spelt and Common Wheat Flours[1]

	CDC Bavaria	Spelt4	Spelt5	Spelt9	Katepwa
			Chemical composition		
Protein (%)	15.50	16.06	16.91	16.43	16.52
Starch (%)	80.1	79.0	78.6	78.5	78.5
Crude fat (%)	1.39	1.28	1.27	1.26	1.06
Ash (%)	0.54	0.54	0.52	0.48	0.59
			Farinograph characteristics		
Water absorption (%)	57.73	61.40	62.02	62.17	64.06
DDT (min)	1.50	1.50	1.50	1.50	3.50
MTI (BU)	80.0	95.0	85.0	100	35.0
Stability (min)	4.5	3.0	4.25	4.0	11.5

[1] Values are shown as dry basis (%db).

Optimized (enriched) straight-dough procedure (AACC 10-10B) was used to evaluate baking quality. Common wheat, Katepwa and commercial flour, Emerald (CSP Food Co.) were used as controls

Bread made from spelt wheat flours (1998 crop) had a lower loaf volume than bread from commercial flour (Table 33). Doughs from spelt wheats, compared to common, wheat were slightly sticky. 99SPELT9 had a larger loaf volume compared to bread from Katepwa while 99SPELT5 had the smallest volume among spelt lines. Spelt bread was slightly darker in crust color than the control bread but was similar in crumb color. Most of the spelt breads had crumb texture scores while bread from 99SPELT9 had a similar texture to the control bread.

The average percent of recovery and flour yield for 11 spelt x common wheat lines (1999 crop) was 98.2% and 71.8%, respectively. Protein content of CDC Bavaria and 99SPELT11 was similar (17.4%, 17.1%) while 99SPELT12 had a lower protein (14.4%) concentration. The protein content of the spelt wheat lines was in the range of 15.1% to 16.8%. 99SPELT18 was high in wet gluten (%) and 99SPELT20 had a high swelling power. The range of protein and starch content in spelt wheat flour was 14.9%-17.2% and 78.7%-85.2%, respectively. 99SPELT11, 18, and 26 were comparable in flour protein content to Katepwa (17.4%). 98SPELT1 was high in starch concentration. 99SPELT26 had a long farinograph dough development time (DDT) and high stability (Table 34).

Bread from 99SPELT23, 25 and 26 had a higher loaf volume than that of Katepwa while 98SPELT1 had the lowest loaf volume. Crust color of spelt x common wheat breads were lighter than control breads, but crumb colors were slightly darker (yellowish). Most of the spelt x common wheat breads from the 1999 crop were dense and had a higher crumb texture value.

Twelve spelt wheat lines, including CDC Bavaria, and check wheat cv. AC Barrie, were used for baking quality evaluations in 2001. The average percent of recovery and flour yield for the eleven spelt wheat lines was 96.6% and 71.6%, respectively. Protein content of spelt wheat flours was in the range of 14.7 - 17.1%. 2000SPELT9 and 20 were high in protein while 2000SPLET17 was high in starch. Starch content was 79.3% to 82.1% in spelt wheat flours. Crude fat was in the range of 0.83 - 1.09%.

For mixograph properties, spelt wheats exhibited short times to peak, low peak values, and thin band widths compared to the check wheat, AC Barrie. Peak time in spelt wheat lines was in the range of 1.08 to 1.5 min compared to 1.51 min for CDC Bavaria. 2000SPELT20 had a larger band width value and sedimentation volume (Table 35). Dough property of spelt wheats obtained from the farinograph was similar with that from the mixograph (Table 36). Spelt wheats had short dough development times (DDT) and poor stabilities compared with AC Barrie.

Breads from spelt wheat lines showed good loaf volumes and were comparable to AC Barrie (Table 37). Dough from spelt wheat was slightly sticky compared with dough

Table 33. Baking Quality of Spelt and Common Wheat Flours

Wheat samples	MT (min)[1]	Baking absorption (%)	Dough handling	Loaf Vol. (cc)[2]	Loaf wt. (g)[3]	Spec. vol. (cc/g)[4]
CDC Bavaria	3.2	59.7	Slightly sticky	818	135.9	6.01
99Spelt4	2.9	61.4	Slightly sticky	813	136.1	5.97
99Spelt5	2.8	62.0	Slightly sticky	705	137.8	5.12
99Spelt9	3.4	62.2	Slightly sticky	878	138.7	6.33
Common wheat						
Katepwa	4.2	64.1	Good	868	140.0	6.20
Commercial flour[5]						
Emerald	3.7	62.5	Good	950	137.9	6.89

[1] Mixing time (min).
[2] Loaf volume (cc).
[3] Loaf weight (g).
[4] Specific volume (cc/g).
[5] Commercially manufactured by CSP Food Co.

Table 34. Chemical composition and farinograph characteristics of Spelt x common wheat derivatives flours

Wheat samples[1]	Chemical composition				Farinograph characteristics			
	Protein (%)	Starch (%)	Crude fat (%)	Ash (%)	Water absorption (%)	DDT (min)	MTI (BU)	Stability (min)
CDC Bavaria	16.56	79.71	1.22	0.48	59.26	1.75	60.0	>14
98Spelt 1	14.93	85.19	1.11	0.52	59.84	1.75	100.0	7.5
98Spelt 5	15.63	82.94	1.10	0.53	61.94	3.0	60.0	6.25
99Spelt 11	17.43	80.43	1.16	0.49	62.33	2.00	60.0	10.0
99Spelt 12	15.13	81.41	1.23	0.55	62.58	2.00	55.0	5.0
99Spelt 17	16.53	79.83	1.13	0.51	63.02	3.5	15.0	>14
99Spelt 18	17.07	79.86	1.18	0.52	62.52	3.0	10.0	11.0
99Spelt 20	16.46	80.15	0.97	0.51	62.65	3.25	50.0	11.0
99Spelt 23	16.00	80.89	0.97	0.49	64.06	2.75	20.0	>14
99Spelt 25	16.03	81.11	1.02	0.51	63.78	3.0	55.0	8.75
99Spelt 26	17.21	78.65	1.38	0.52	62.86	5.5	10.0	>14
Common wheat								
Katepwa	17.43	81.44	0.96	0.63	66.00	3.5	25.0	11.75

[1]1999 Spelt YT2 Crops.

Table 35. Physicochemical properties of wheat meal from Spelt wheat lines

Wheat line[1]	Mixograph properties					Sedimentation (ml)	Falling number
	Peak time (min)	Peak value (%)	Slope (%/min)	Band width (%)	Area(% Tq*min)		
Barrie	2.92	66.45	-2.14	19.45	397.65	64.0	428
CDC Bavaria	1.51	66.15	-7.24	7.35	378.10	53.0	307
99Spelt 9	1.43	61.15	-7.78	6.60	349.05	47.8	248
2000Spelt 5	1.50	61.45	-7.19	6.60	347.20	43.5	315
2000Spelt 6	1.15	58.45	-7.46	5.70	325.20	28.5	301
2000Spelt 8	1.29	62.10	-7.89	6.15	350.35	35.5	348
2000Spelt 9	1.46	59.30	-6.81	8.20	344.95	41.8	373
2000Spelt 17	1.37	62.70	-8.42	6.15	353.10	42.3	333
2000Spelt 20	1.38	63.05	-6.39	8.15	363.85	47.3	353
2000Spelt 21	1.44	59.75	-6.28	7.00	343.55	31.0	306
2000Spelt 22	1.08	56.60	-8.02	5.40	310.00	28.3	353
2000Spelt 25	1.22	60.20	-7.54	5.05	331.65	27.3	382
2000Spelt 29	1.22	62.75	-9.03	4.90	340.20	35.0	339

[1] 2000 Spelt YT1 crop composite.

Table 36. Farinograph properties of flour from Spelt wheat lines

Wheat line[1]	Water absorption (%)	DDT (min)	MTI(BU)	Stability (min)
Barrie	62.94	4.50	30.0	13.00
CDC Bavaria	58.05	2.25	60.0	6.25
99Spelt 9	59.67	2.50	70.0	4.75
2000Spelt 5	60.82	1.50	80.0	3.75
2000Spelt 6	58.82	0.75	115.0	2.00
2000Spelt 8	60.80	1.25	95.0	2.50
2000Spelt 9	62.11	1.00	100.0	3.00
2000Spelt 17	60.53	1.50	100.0	3.50
2000Spelt 20	61.00	2.25	80.0	5.00
2000Spelt 21	60.62	0.75	135.0	1.75
2000Spelt 22	61.43	1.25	90.0	2.25
2000Spelt 25	61.60	0.75	145.0	1.75
2000Spelt 29	61.08	0.75	120.0	2.50
Control flour[2]	62.88	4.25	40.0	11.00

[1] 2000 Crop composite of Spelt YT1.

[2] Flour from four wheat composite (2000) including Barrie, Laura, Elsa, and Boblin.

Table 37. Baking quality of flour from Spelt wheat lines

Wheat line[1]	MT (min)[2]	Baking absorption (%)	Dough handling	Loaf vol.(cc)[3]	Loaf wt. (g)[4]	Spec.vol. (cc/g)[5]
Barrie	3.3	59.9	Good	1093	140.29	7.79
CDC Bavaria	2.9	55.1	Slightly sticky	1028	137.68	7.46
99Spelt 9	3.0	56.7	Slightly sticky	1040	137.63	7.56
2000Spelt 5	2.8	57.8	Sticky	1100	138.18	7.96
2000Spelt 6	2.3	55.8	Very sticky	1005	137.10	7.33
2000Spelt 8	3.0	57.8	Sticky	1068	138.80	7.69
2000Spelt 9	2.6	59.1	Sticky	1083	140.56	7.70
2000Spelt 17	2.8	57.5	Slightly sticky	1060	138.71	7.64
2000Spelt 20	3.1	58.0	Slightly sticky	1120	139.18	8.05
2000Spelt 21	2.8	57.6	Slightly sticky	1103	139.17	7.92
2000Spelt 22	2.2	58.4	Very sticky	1035	140.00	7.39
2000Spelt 25	2.7	58.6	Sticky	1020	140.95	7.24
2000Spelt 29	2.9	58.1	Sticky	1145	139.80	8.19
Control flour[6]	3.8	59.9	Good	1128	137.23	8.22

[1] 2000 Spelt YT1 crop composite.
[2] Mixing time (min).
[3] Loaf volume (cc).
[4] Loaf weight (g).
[5] Specific volume (cc/g).
[6] Flour from four wheat composite (2000 crop) including Barrie, Laura, Elsa, and Roblin.

from the control flour, but this stickiness disappeared and dough handling was improved during the dough fermentation period. Loaf volume was high in 2000SPELT29 and 20. Especially, 2000SPELT29 bread had a higher loaf volume than the control bread. Spelt wheat breads had slightly larger and coarser grains in the crumb structure compared with AC Barrie, which had soft, silky, and small-elongated grains in the crumb structure. Larger crumb grains were found in bread from 2000SPELT22, 25, and 29. There was no significant difference in crust color among spelt wheat breads (Table 38). Most of the breads from spelt wheat had a slightly yellowish crumb compared with the control bread. On the other hand, bread from 2000SPELT8, 9, and 20 had a white crumb similar to that of the control bread. Crumb texture was highly correlated with loaf volume. 2000SPELT9 and 20 had lower crumb texture scores due to high loaf volumes. Crumb texture of spelt wheat breads was comparable to that of AC Barrie and the control bread.

A.4.1.2. Noodle Product

Spelt wheat flour was mixed with a salt solution (1.5 % sodium chloride, 35 % absorption) for white noodle production and AC Reed, soft wheat was used as a control for noodle quality. Color of flour and dough sheet was determined using a HunterLab MiniScan XE, standardized with a white color standard. Texture profile of noodle strips (6 strips) was measured using a TMS-90 Texture Test System installed with a TPA-1 Cell (Food Technology Corp.).

Noodle from CDC Bavaria and 99SPELT9 (1999 crop) was similar in texture profile to that from soft wheat, which is commonly used for noodle production. 99SPELT4 and 5 had slightly lower values for noodle hardness but their gumminess and chewiness were similar to that from 99SPELT9 and Katepwa flours. CDC Bavaria noodles were slightly lighter in color compared to other spelt wheats, which had a slightly yellowish color. Overall, spelt wheat had an acceptable noodle quality. Brightness (whiteness) of flour and fresh dough sheet from spelt x common wheat lines and cv. Katepwa CWRS wheat (1999 crop) decreased as yellowness increased. Brightness increased after doughs were cooked for 6 min in boiling water. Cooked dough sheets from CDC Bavaria and 99SPELT26 had low L-values and increased yellowness compared to cooked dough sheets from five other spelt x common wheat lines (11, 12, 23, 25, 26). Noodles from 99SPELT11 and 12 were slightly stronger in texture while noodles from 99SPELT23, 25 and 26 were comparable to Katepwa. Three spelt x common wheat lines, 99SPELT12, 23 and 26 had slightly higher, but comparable, values to the control, in texture profile of cooked dough sheets (Table 39). Overall, noodles from 99SPELT17, 12 and 25 scored high for eating quality (Table 40).

Four spelt wheat lines (2000SPELT series) including CDC Bavaria, and AC Barrie CWRS as a control, were used to produce noodles. Three spelt wheat lines, 2000SPELT8, 9, and 20 were selected based on their flour color as measured with a HunterLab apparatus. Since whiteness (brightness) is preferred in white-salted noodle products, the three spelt wheats were selected based on their high L- and low b-values.

Table 38. Color of crust and crumb of bread from Spelt wheat flours

Wheat line[1]	Crust color[2]			Crumb color[2]			Crumb texture (N)
	L	a	b	L	a	b	
Barrie	29.62	11.20	10.84	78.20	0.13	13.50	308.02
CDC Bavaria	29.82	11.46	10.83	76.88	-0.03	14.47	320.48
99Spelt 9	30.67	11.69	11.56	76.97	-0.09	15.37	286.22
2000Spelt 5	31.19	11.75	11.57	76.28	-0.23	15.19	265.19
2000Spelt 6	30.87	11.21	11.40	72.06	0.22	16.33	338.02
2000Spelt 8	31.85	11.75	12.34	75.56	-0.05	13.97	267.13
2000Spelt 9	31.74	11.57	11.90	74.11	-0.18	13.55	296.82
2000Spelt 17	32.08	11.87	12.28	76.29	-0.14	15.80	245.28
2000Spelt 20	30.03	10.90	11.14	74.85	-0.16	12.99	236.75
2000Spelt 21	30.71	11.24	11.24	75.48	-0.10	15.21	277.88
2000Spelt 22	32.48	11.63	11.81	69.22	-0.08	15.55	325.75
2000Spelt 25	32.30	11.80	12.10	73.28	-0.11	16.23	269.82
2000Spelt 29	30.93	11.14	10.83	73.46	-0.06	15.90	242.04
Control flour[3]	29.14	10.56	9.83	77.04	0.18	13.89	285.49

[1] 2000 Spelt YT1 crop composite.
[2] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue).
[3] Flour from four wheat composite (2000 crop) including Barrie, Laura, Elsa, and Roblin.

Table 39. Texture profile of dough sheet from Spelt x common wheat lines

	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]
Common wheat						
Katepwa	69.96	1.15	0.60	0.04	80.68	3.69
AC Reed	67.96	0.60	0.78	0.03	40.93	1.72
Spelt wheat[2]						
CDC Bavaria(Trt 2)	61.66	1.07	0.81	0.03	65.86	2.78
98 Spelt 1(Trt 3)	49.75	1.01	0.51	0.03	49.77	2.09
98 Spelt 5(Trt 5)	56.93	0.96	0.62	0.03	54.50	2.30
99 Spelt 11(Trt 7)	82.29	0.89	0.81	0.04	72.70	3.28
99 Spelt 12(Trt 8)	71.00	1.00	0.73	0.04	71.15	3.44
99 Spelt 17(Trt13)	58.84	0.91	0.54	0.03	53.73	2.27
99 Spelt 18(Trt 14)	60.62	1.00	0.57	0.03	60.87	2.58
99 Spelt 20(Trt 16)	61.93	1.00	0.53	0.04	61.92	3.00
99 Spelt 23(Trt 19)	70.78	1.03	0.56	0.04	73.09	3.39
99 Spelt 25(Trt 21)	54.28	1.09	0.50	0.03	58.89	2.28
99 Splelt 26(Trt 22)	71.43	1.12	0.67	0.04	80.41	3.89
LSD (p<0.05)	7.778	0.170	0.132	0.009	13.805	1.122

[1] HD; hardness (N), CO; cohesiveness, AD; adhesiveness (N-cm), SP; springiness (cm), GU; gumminess (N), CH; chewiness (N-cm).
[2] 1999 Spelt YT2 Crops.

Table 40. Eating quality of noodles made from Spelt x common wheat derivatives[1]

Wheat	Brightness	Yellowness	Surface smoothness	Softness	Elasticity
Common wheat					
Katepwa	7.0a	6.0a	7.0a	7.0a	7.0a
Spelt wheat[2]					
CDC Bavaria	6.5a	6.0a	7.0a	6.5a	7.0a
98 Spelt 1	6.5a	6.0a	7.0a	6.5a	7.0a
98 Spelt 5	7.0a	6.5a	7.0a	6.5a	7.0a
99 Spelt 11	6.0a	5.0b	7.0a	7.0a	7.0a
99 Spelt 12	7.5ab	6.5a	7.0a	7.0a	7.0a
99 Spelt 17	8.0b	7.0a	7.0a	7.0a	7.0a
99 Spelt 18	7.0a	6.0a	7.0a	6.0a	6.0a
99 Spelt 20	6.5a	6.5a	6.5a	6.5a	7.0a
99 Spelt 23	7.0a	6.0a	7.0a	7.0a	6.5a
99 Spelt 25	7.5ab	7.0a	7.0a	6.0a	7.5a
99 Spelt 26	6.5a	6.5a	7.0a	7.0a	7.0a

[1] Nine point scale, 1=dislike extremely and 9=like extremely. Means in a column with the same letters are not significantly different at p=0.05.
[2] 1999 Spelt YT2 Crops.

The three spelt wheats showed very good noodle properties in terms of color and texture. Whiter color and soft texture, are desirable for the production of white salted noodles. Noodles from spelt wheats were comparable with those from soft wheat in overall texture profile, but were slightly less desirable for hardness and gumminess. Cooking loss of spelt noodles was positively related to the starch content of the flour sample (Table 41). Cooking loss was slightly lower in spelt wheat noodles compared with soft wheat noodles. Whiteness (brightness) of the noodle product was improved during cooking (Table 42). Cooked dough was whiter and less yellow than fresh dough as indicated by increasing L- and decreasing b-value. It was hard to detect visual differences between control (soft wheat) and spelt noodles even though there were small differences in their color values.

The texture profile of dried noodles was measured after the noodle was kept in a plastic bag and stored at room temperature for 3 months (Table 43). Spelt noodles had a similar texture profile to noodles from CWRS and SW wheats. The textural changes during the storage period were investigated using noodles from CWRS wheat (Katepwa). The noodle hardness increased rapidly within a week while the rest of the texture profile remained stable during the period of storage at room temperature (Figure 17). A positive relationship was found between hardness and gumminess.

A.4.1.3. Pasta products

Six of the spelt x common wheat lines (1999 SpeltYT2 crop) which had higher yellowness and texture values were selected for pasta processing. Pasta was prepared using a small-scale PastaMatic device (SIMAC Appliances Co., New York, NY). Dough was prepared in a separate mixer and shaped using a Tagliatella media disc. Pasta was dried at room temperature for 20-22 hr and stored in plastic bags prior to quality evaluation.

Pasta from 99SPELT26 scored high in eating quality. Pasta from selected lines, with the exception of 99SPELT 20 and 23, was acceptable and scored higher than pasta from semolina (Table 44). Texture profile of spelt pasta was still comparable to durum pasta but slightly harder after storage for 2 months at room temperature (Table 45).

Six of the spelt wheat lines (2000 SpeltYT1 crop), which were high in b-value (yellowish flour color), were selected for pasta processing. Pasta was prepared using an absorption of 36% for spelt wheats and 38% for durum semolina. Pasta from spelt wheats, except CDC Bavaria, was similar in texture profile with pasta from CWAD semolina (Table 46). Hardness was slightly higher in pasta from 2000SPELT20 and 21. Cooking loss in pasta from spelt wheats, except 2000SPELT17 and 25 was very similar with that of the control pasta. Cooking loss of spelt pasta was positively related to the starch content of the flour. Cooking loss was high in 2000SPELT17 (high starch content) and low in 2000SPELT25 (low starch content). Pasta products from spelt wheats, except CDC Bavaria, were comparable with durum pasta in sensory evaluations (Table 47). CDC Bavaria pasta was soft and had a dull whitish color, resulting in a lower score. Spelt pasta compared with durum pasta (control), especially from 2000SPELT17, 21 and 22, scored high in the

Table 41. Texture profile of noodle products from spelt wheat lines

Wheat sample	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]	Cooking loss (%)
AC Reed	224.92	0.556	0.348	0.035	125.43	5.356	5.49
Barrie	298.13	0.550	0.750	0.040	164.03	7.944	5.34
Spelt wheats							
CDC Bavaria	241.94	0.529	0.138	0.040	127.85	6.192	4.72
2000Spelt8	170.42	0.609	0.101	0.040	102.88	4.982	4.19
2000Spelt9	180.40	0.618	0.098	0.040	107.25	5.193	4.23
2000Spelt20	193.60	0.583	0.101	0.040	112.82	5.465	4.37
LSD ($p<0.05$)	54.403	0.031	0.439	0.004	28.692	1.416	--

[1] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=4.

Table 42. Color of dough sheets prepared from Spelt wheat lines

Wheat sample	HunterLab Color[1]					
	Fresh dough			Cooked dough		
	L	a	b	L	a	b
AC Reed	81.61	-0.22	18.74	86.00	-2.20	13.27
Barrie	77.94	1.93	20.75	82.58	-1.06	17.02
Spelt wheats						
CDC Bavaria	78.56	1.05	20.50	83.99	-1.80	15.55
2000Spelt8	78.52	1.36	21.70	83.29	-1.46	17.41
2000Spelt9	78.32	1.24	20.60	83.44	-1.33	16.51
2000Spelt20	78.19	1.02	19.72	83.25	-1.44	16.36

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue).

Table 43. Texture Profile of Noodle Products Prepared from Soft, CWRS and Spelt Wheats after the Period of Storage at Room Temperature[1]

Wheat sample	HD[2]	CO[2]	AD[2]	SP[2]	GU[2]	CH[2]
AC Reed (soft wheat)	15.63	0.64	0.0	0.01	9.93	0.17
Katepwa (CWRS)	17.58	0.64	0.0	0.02	11.35	0.36
Spelt wheat						
98 Spelt1	15.47	0.62	0.0	0.01	9.51	0.21
98Spelt12	16.77	0.68	0.0	0.02	11.51	0.31
99Spelt17	14.49	0.74	0.0	0.01	10.66	0.23
99Spelt25	15.79	0.67	0.0	0.02	10.44	0.28

[1] Noodle was stored for 3 months at RT and cooked for 6 min in boiling water.
[2] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=4.

Table 44. Eating quality of pasta made from Spelt wheats[1]

Wheat	Firmness	Color	Stickiness	Flavor	Appearance
Semolina	2.6b	3.5a	3.1a	3.5a	2.5b
Common wheat					
Katepwa	3.4a	3.0a	3.3a	3.8a	3.5a
Spelt wheat[3]					
99Spelt 11	3.5a	3.1a	3.5a	3.5a	3.1ab
99Spelt 12	3.4a	2.8a	3.8a	3.3a	3.9a
99Spelt17	1.8b	2.1b	2.5b	3.0a	1.1c
99Spelt 23	2.3b	3.1a	3.3a	3.0a	2.5b
99Spelt 25	3.3a	2.5b	2.8b	3.1a	2.8b
99Spelt 26	3.9a	3.1a	3.5a	3.3a	3.5a

[1] 4 Scales; 4 = good, 3 = fair, 2 = poor, 1 = very poor. Means in a column with the same letters are not significantly different at p=0.05.
[2] 1999 Spelt YT2 Crops.

Table 45. Texture profile of Pasta Products Prepared from Durum, Spelt Wheats after the Period of Storage at Room Temperature[1]

Wheat sample	HD[2]	CO[2]	AD[2]	SP[2]	GU[2]	CH[2]
Durum	21.01	0.36	0.0	0.04	7.60	2.29
Katepwa (CWRS)	24.59	0.43	0.0	0.05	10.69	0.61
Spelt wheat						
99Spelt11	24.59	0.42	0.0	0.06	10.40	0.61
99Spelt23	27.03	0.41	0.0	0.06	11.21	0.79
99Spelt26	24.75	0.42	0.0	0.05	10.38	0.63

[1] Pasta products were stored in a plastic bag for 2 months at RT and cooked for 20 min in boiling water.

[2] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=4.

Table 46. Texture profile of pasta prepared from semolina and Spelt wheat lines

	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]	Cooking loss (%)
Semolina, Durum	44.49	0.338	0.016	0.070	15.03	1.146	5.58
Spelt wheats[2]							
CDC Bavaria	39.65	0.376	0.024	0.068	15.06	1.130	5.25
2000spelt17	42.37	0.434	0.051	0.063	18.40	1.297	6.37
2000spelt20	49.50	0.380	0.018	0.085	18.87	1.705	5.60
2000spelt21	48.72	0.373	0.027	0.080	18.25	1.611	5.27
2000spelt22	44.13	0.399	0.017	0.070	17.64	1.365	5.59
2000spelt25	46.77	0.473	0.048	0.070	22.17	1.971	4.91
2000spelt29	44.84	0.446	0.042	0.068	20.05	1.491	5.43
LSD ($p<0.05$)	4.150	0.031	0.022	0.008	2.608	0.431	--

[1] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=4.
[2] 2000 Spelt YT1 crop composite.

Table 47. Eating quality of pasta products processed from spelt wheat lines[1]

	Appearance	Color	Flavor	Stickiness	Firmness
Semolina, Durum	3.8a[2]	3.8a	3.3a	3.0a	3.5a
Spelt wheats					
CDC Bavaria	3.5a	2.6b	2.8b	3.3a	2.5b
2000spelt17	3.8a	3.9a	3.6a	3.1a	3.4a
2000spelt20	3.8a	3.1b	3.5a	3.3a	2.8a
2000spelt21	3.6a	3.8a	3.6a	3.4a	3.3a
2000spelt22	3.6a	3.8a	3.5a	3.5a	3.8ac
2000spelt25	3.4a	3.8a	3.5a	3.0a	3.1a
2000spelt29	3.4a	3.8a	3.8a	3.1a	2.6b

[1] 4 = good, 3 = fair, 2 = poor, 1 = very poor.
[2] Means in a column with the same letters are not significantly different.

overall sensory evaluation. Pasta stickiness was negatively related to cohesiveness and adhesiveness in the texture profile. Since selection of spelt wheats for pasta was based on flour color, pasta prepared from them scored the same as the control pasta for color in the sensory evaluation. Overall, the yellowness and a certain amount of firmness in mouth-feel were desirable factors for spelt pasta products.

A.4.2. Baking and Malting Quality of Emmer Wheats

A.4.2.1. Baking Quality of Emmer Wheat with Natural Improver

Emmer wheat (Emmer19) and WB881 durum wheat were tested for their bread baking quality. WB881 had a high SDS-sedimentation value, but similar chemical composition and farinograph characteristics to the emmer wheat. Common wheat cv. Katepwa was used for comparative purposes (Table 48).

Since bread from emmer wheat has previously had a lower loaf volume and a dense crumb structure, the natural improver, ascorbic acid (AA), was added to the flour in combination with a long fermentation time, to increase loaf volume. Levels of ascorbic acid were 100, 150 and 200 ppm. The commercial flour, Emerald, was used as a control. The loaf volume of Emmer19 and WB881 was greatly improved by increasing the level of ascorbic acid. WB881 had the highest loaf volume among wheat samples, including the control, when the level of AA was 100ppm. Also, bread from Emmer19 produced with 100ppm AA was larger in loaf volume than breads from Katepwa and commercial flour.

To develop a yellow-pigmented baking wheat, Emmer19 was crossed with the strong gluten semidwarf durum WB881. The lines were screened and eight of the lines in 2000 were selected for baking tests. The parents in the cross, Emmer19 and WB881, and Kyle, CWAD wheat were used as controls in baking tests.

Bread was prepared using a straight-dough baking procedure with long fermentation time (AACC 10-09). Emmer x durum wheat lines had longer mixing times to develop dough than Emmer19 and durum wheat (Table 49). Breads from emmer x durum wheat lines had higher oven springs and higher loaf volumes than control breads prepared from common wheat (Table 50). These loaf volumes were negatively related to the value in crumb texture. Most of the emmer x durum wheat lines, except 2000EB10, showed higher loaf volumes than WB881. Breads from 2000EB1, 14, 23, and 28 had high loaf volumes compared with Emmer19 and the control. Emmer x durum wheat breads had fine, soft, silky, and elongated grains in crumb structure. There was no significant difference in crust color. Crumb color of bread was highly correlated with color from the corresponding flour (Table 51). All breads from emmer x durum wheat lines had a yellowish crumb color compared with the control bread. Crumb color of Emmer19 was comparable with that of 2000EB23, 28, and 29.

Table 48. Chemical Composition and Farinograph Characteristics of Emmer and WB881 Wheat

Wheat samples	Chemical composition of whole wheat		
	Protein (%)	SDS sedimentation	Falling number
Emmer19	17.28	33.0	419
WB881 (Durum)	17.50	46.0	499
Dragon	17.77	24.0	428
Common wheat			
Katepwa	17.64	60.5	387

Wheat samples	Chemical composition of flour			
	Protein (%)	Starch (%)	Crude fat (%)	Ash (%)
Emmer19	16.94	77.0	1.11	0.84
WB881 (Durum)	17.33	77.7	1.07	0.95
Dragon	17.22	79.2	0.74	0.90
Common wheat				
Katepwa	17.83	79.6	0.87	0.63

Wheat samples	Farinograph characteristics			
	Water absorption (%)	DDT (min)	MTI (BU)	Stability (min)
Emmer19	66.32	1.5	75	4.0
WB881 (Durum)	67.46	3.0	55	12.5
Katepwa	66.08	1.75	40	4.25

Table 49. Chemical composition and farinograph characteristics of Emmer/Durum wheat lines

Wheat line[1]	Protein (%)	Starch (%)	Crude fat (%)	Ash (%)	TDF (%)
Emmer 19	16.19	80.01	1.07	0.79	2.50
WB 881	15.91	81.31	0.98	0.84	2.77
Kyle	15.18	80.25	0.87	0.71	2.71
2000EB 1	17.61	77.62	1.15	0.79	2.81
2000EB 4	17.59	79.05	1.03	0.80	2.36
2000EB 7	16.81	77.64	1.13	0.75	2.63
2000EB10	16.56	76.44	1.05	0.90	2.81
2000EB14	15.99	80.03	1.03	0.73	1.85
2000EB23	17.08	76.40	1.08	0.80	2.33
2000EB28	15.89	78.74	1.01	0.72	2.42
2000EB29	15.74	80.21	1.00	0.75	2.36
Control flour[2]	17.00	80.91	1.17	0.61	2.79

	Farinograph Characteristics			
	Water absorption (%)	DDT (min)	MTI	Stability
Emmer 19	60.87	1.75	95.0	3.75
WB 881	63.50	4.00	50.0	7.00
Kyle	63.10	2.25	75.0	3.25
2000EB 1	65.42	4.75	40.0	9.50
2000EB 4	62.84	5.50	25.0	13.00
2000EB 7	61.83	3.75	55.0	6.50
2000EB10	63.60	4.00	35.0	13.00
2000EB14	61.87	5.00	25.0	13.50
2000EB23	63.01	4.50	35.0	14.00
2000EB28	63.70	5.50	25.0	14.50
2000EB29	62.56	6.00	30.0	15.00

[1] 2000 Emmer YT crop composite.
[2] Flour from four wheats (2000 crop) including Barrie, Laura, Elsa, and Roblin.

Table 50. Bread baking quality of flour from Emmer/Durum wheat lines

Wheat line[1]	MT (min)[2]	Baking absorption (%)	Dough handling	Loaf vol.(cc)[3]	Loaf wt. (g)[4]	Spec.vol. (cc/g)[5]
Emmer 19	2.2	57.9	very sticky	898	127.61	7.03
WB 881	3.2	60.5	good	820	129.71	6.32
Kyle	3.1	60.1	sticky	553	130.82	4.22
2000EB 1	4.1	62.4	good	1013	127.75	7.93
2000EB 4	4.2	59.8	good	843	128.61	6.55
2000EB 7	3.5	58.8	slightly sticky	873	127.41	6.85
2000EB10	4.6	60.6	good	780	130.83	5.96
2000EB14	4.1	58.9	good	905	127.96	7.05
2000EB23	3.7	60.0	good	940	127.99	7.34
2000EB28	4.4	60.7	good	913	129.37	7.05
2000EB29	4.2	59.6	good	843	129.26	6.52
Control flour[6]	3.6	59.9	good	815	127.90	6.37

[1] 2000 Emmer YT crop composite.
[2] Mixing time (min).
[3] Loaf volume (cc).
[4] Loaf weight (g).
[5] Specific volume (cc/g).
[6] Flour from four wheat composite (2000 crop) including Barrie, Laura, Elsa, and Roblin.

Table 51. Color of crust and crumb of bread from Emmer/Durum wheat lines

Wheat line[1]	Crust color[2]			Crumb color[2]			Crumb texture (N)
	L	a	b	L	a	b	
Emmer 19	48.30	12.71	20.71	71.00	0.50	14.37	298.4
WB 881	49.65	14.97	22.31	75.29	0.52	20.34	390.1
Kyle	44.42	12.52	20.03	72.77	1.04	21.54	727.6
2000EB 1	51.91	13.41	22.75	73.08	0.51	16.66	275.5
2000EB 4	56.93	12.53	24.90	75.23	0.61	17.66	346.7
2000EB 7	54.44	12.52	23.46	74.49	0.44	16.69	324.4
2000EB10	53.11	14.00	23.53	75.05	0.54	17.75	363.3
2000EB14	49.33	12.49	21.58	73.57	0.53	16.73	311.9
2000EB23	52.90	11.97	22.64	72.93	0.59	14.86	333.6
2000EB28	54.18	13.03	23.65	74.81	0.43	15.38	286.3
2000EB29	52.77	13.44	23.08	73.93	0.45	14.66	352.0
Control flour[3]	59.46	10.26	24.06	75.17	0.57	14.01	355.4

[1] 2000 Emmer YT crop composite.
[2] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue).
[3] Flour from four wheat composite (2000 crop) including Barrie, Laura, Elsa, and Roblin

Four emmer x durum wheat lines selected from the 2000 baking tests were re-evaluated in 2001. The results were similar in 2000 with the exception of slightly lower loaf volumes.

A.4.2.2. Malted Emmer Wheats

The emmer wheats Emmer19 and Vernal, and Einkorn wheat TM23 along with malting barley, Kendall, as control, were malted. Wheats used for malting are described in Table 52. Emmer and Einkorn was similar in grain color. Dehulled emmer showed no water sensitivity while hulled grain slowly absorbed water resulting in lower germination energy and high water sensitivity.

The chemical composition and enzyme activities of unmalted and malted emmer, einkorn and malting barley are presented in Table 53. Emmer malt was slightly darker in color than einkorn and barley malts. There was no significant difference in starch content among wheats. The hydrolysis of starch, protein and ∃-glucan on malting resulted in increase in soluble carbohydrates, soluble protein and reducing sugars and decrease in ∃-glucan. Malting significantly increased enzyme activity including ∀-amylase and proteolytic activity. The Kolbach index, soluble/total protein ratio, is used as an index of modification by malting (Bamforth and Barclay 1993). A higher ratio indicates more extensive breakdown of the protein by proteolytic enzymes. Emmer wheat was more susceptible to those enzymes than the malting barley. Unmalted emmer wheat had a very low ∀-amylase activity but considerable proteolytic activity. The ∀-amylase activity increased 316-fold in dehulled emmer malt and 164-fold in hulled emmer malt. Barley malt had higher reducing sugars and ∀-amylase activity than wheat malts. The ∀-amylase activity of emmer malt was in between that of einkorn and barley malt. Proteolytic activity was markedly increased in emmer malt, especially in Emmer19. The amino acid composition of unmalted and malted emmer and barley are presented in Table 54. There were no significant differences in individual amino acids even though aspartic and glutamic acids were slightly decreased in malted grains. In the brewing process, free amino nitrogen of the wort is commonly reported and is of greater importance for yeast nutrition.

Malt extract from emmer compared to barley, had a similar protein but higher starch content (Table 55). Malt extract from Vernal emmer had a higher starch content which is less soluble in 70% ethanol than that of Emmer19.The proteolytic activity in dehulled emmer was twice that in malt extract from hulled barley.

A.4.3. Quality Evaluation of Cookie and Cake from Einkorn Wheats

Most einkorn breeding lines had excellent cookie baking qualities, including a desirable yellow crumb color, volume and texture but some of the lines had an after-taste in the product. Einkorn cookies were kept in a plastic bag for 3 weeks to investigate the changes in color and cookie weight (Figure 18). The changes in cookie weight and L-values were less in einkorn cookies compared to the control cookies prepared from commercial cake and pastry flour (Robin Hood Co.). The weight loss in control cookies

Table 52. Description of Emmer and Einkorn Wheat Used for Malting

	Grain with hull			Grain without hull		
	Emmer19	Vernal	TM23	Emmer19	Vernal	TM23
Seed color, L	52.09	54.75	53.49	39.75	38.96	43.39
Germination energy, %	0	0	85.5	100	100	99.5
Water sensitivity, %	64.5	30.5	42	-	-	-0.5
Germination capacity, %	93	85	49	99	100	100
Extract, %	1.14	1.77	1.14	1.35	1.66	2.28
Spec. gravity	1.006	1.008	1.006	1.006	1.007	1.011

Table 53. Composition and Enzyme Activity of Unmalted and Laboratory- Malted Emmer, Einkorn Wheats and Barley

	Grain with hull								Grain without hull					
	Unmalted grain				Malted grain				Unmalted grain			Malted grain		
	Emmer19	Vernal	TM23	Kendall	Emmer19	Vernal	TM23	Kendall	Emmer19	Vernal	TM23	Emmer19	Vernal	TM23
Steep moisture (%)	--	--	--	--	49.76	48.44	48.43	43.3	--	--	--	45.09	41.67	42.99
Color (L)	71.04	72.65	76.59	82.97	60.25	61.63	65.01	71.05	78.40	78.21	84.91	71.49	73.72	77.20
Ash (%)	3.74	4.04	4.19	2.64	3.47	3.72	4.00	2.31	2.03	2.15	2.16	1.93	2.15	2.15
Total protein (T, %)	13.31	13.83	13.11	14.01	13.59	14.62	13.92	13.71	16.34	17.11	16.71	17.70	17.83	17.85
Starch (%)	49.7	48.9	49.8	58.35	43.6	44.0	43.3	48.5	62.8	63.0	62.9	55.4	58.8	60.4
Ǝ-glucan (%)	0.43	0.50	0.48	4.19	0.21	0.30	0.25	0.28	0.52	0.53	0.41	0.23	0.26	0.20
Soluble carbohydrates (%)	3.4	2.9	3.2	3.7	12.0	8.1	11.3	19.6	4.1	3.4	3.9	12.6	8.9	8.1
Soluble protein (S, %)	5.78	7.47	6.76	4.14	6.65	7.57	7.05	5.08	7.57	9.80	9.27	8.04	9.13	8.35
S/T (%, Kolbach index)	--	--	--	--	48.9	51.8	50.6	37.1	--	--	--	45.4	51.2	46.8
Viscosity (cps)	--	--	--	--	1.84	2.20	3.27	1.53	--	--	--	1.94	2.01	2.93
Reducing sugars (%)	0.21	0.22	0.23	0.20	2.15	1.06	1.11	7.34	0.19	0.20	0.17	1.95	1.31	0.76
∀-amylase (Ceralpha units g^{-1})	0.10	0.21	0.10	0.09	27.01	12.26	6.25	95.89	0.14	0.12	0.11	48.72	34.21	5.34
Proteolytic activity (mg npn/100g)	34	58	63	34	176	96	97	90	18	35	66	500	130	230

Table 54. Amino Acid Composition of Unmalted and Laboratory-malted Emmer Wheat and Barley[1]

Amino acid	Emmer 19		Kendall	
	Unmalted	Malted	Unmalted	Malted
Lysine	2.3	2.7	3.1	3.5
Methionine	1.2	1.2	1.4	1.3
Threonine	2.9	3.2	3.1	3.6
Isoleucine	3.3	3.4	3.4	3.7
Leucine	6.1	6.1	6.7	6.8
Valine	6.2	6.7	7.6	8.2
Phenyalanin	5.4	5.3	5.8	6.0
Tyrosine	1.9	2.1	2.3	2.4
Histidine	2.2	2.3	2.1	2.3
Alanine	3.9	3.9	4.3	4.8
Arginine	4.9	5.4	5.4	4.7
Aspartic acid	5.3	7.4	6.4	8.1
Glutamic acid	30.4	27.2	24.3	20.3
Glycine	3.8	3.8	3.8	3.9
Proline	10.2	9.5	11.2	11.2
Serine	4.8	4.6	4.2	4.1
Total	95.0	95.0	95.0	95.0

[1] Tryptophan and Cystine were not included.

Table 55. Composition and Enzyme Activity of Malt Extracts from Emmer and Einkorn Wheats

	Grain with hull				Grain without hull		
	Emmer19	Vernal	TM23	Kendall	Emmer19	Vernal	TM23
Protein (%)	10.80	9.33	8.85	9.22	7.43	6.73	5.94
Starch (%)	7.8	13.1	15.6	4.8	9.4	13.9	27.1
Soluble carbohydrate (total, %)	100.3	91.0	77.2	106.6	104.2	99.3	62.1
Soluble protein (%)	8.44	5.94	5.80	7.06	5.08	3.93	2.56
Reducing sugar (%)	36.29	35.03	32.68	40.17	34.68	35.88	25.69
∃-glucan (%)	0.12	0.12	0.12	0.19	0.12	0.13	0.12
∀-amylase (ceralpha units/g)	0.07	0.05	0.11	0.08	0.02	0.00	0.10
Proteolytic activity (mg npn/100g)	-	-	-	21	42	-	-

was twofold that of einkorn cookies. The Hunter b-value of einkorn cookies decreased rapidly within the first week and then was stable for the remaining two weeks.

Einkorn wheats including TM23, CDC Uno and several breeding lines (1999 crop) were tested for cake production along with commercial cake and pastry flour as controls (Table 56). Einkorn cakes were similar in volume and internal cell structure to that those made with commercial cake flour with the exception of cell walls, which were slightly thicker in einkorn cakes. Einkorn cake had a creamy yellow crumb color that is a desirable characteristic in many kinds of cake products. Einkorn cakes were very moist, tender and soft while cake from commercial flour had slightly dry but very tender and soft texture with a bright white crumb color. Even though most of cakes from einkorn lines had very good quality, cakes from CDC Uno, 98EINK6 and 15 had an undesirable after-taste or mouth-feel. Cake from TM23 and 98EINK31 had the best quality of the remaining wheat samples.

Eleven einkorn wheat lines evaluated in the field in 2000, including TM23 and Uno, were evaluated for their cake baking quality (AACC 10-90). Protein of einkorn wheat lines was in the range of 17.2% to 20.8%. Protein content was high in flours from Uno, 98EINK1, 98EINK31 and 2000EINK11. There was no significant difference in chemical composition of einkorn wheat flours while starch content was slightly lower in Uno and 98EINK1.

Einkorn cakes , with the of those from TM23, were slightly higher in volume compared to the control cakes (Table 57). Einkorn cakes were similar in internal cell structure to the control cakes from commercial cake flour. Even though most of cakes prepared from einkorn wheats had very good quality, some of cakes had an undesirable after-taste or mouth-feel as mentioned earlier. Average sensory score of einkorn cake was high in 2000EINK11 and 22 followed by TM23, 98EINK31, and 2000EINK3 (Table 58). Strong after-taste was detected in cake from Uno resulting in a low score. No after-taste was detected in cakes from 98EINK31 and 2000EINK22. High acceptability was found in cakes from 2000EINK11 and 22 even though 2000EINK11 cake had a slight after-taste. Overall, TM23, 98EINK31, 2000EINK11, 22 and 3 showed good baking quality with high scores in the sensory evaluation.

A.4.4. Quality Test of Puffing Wheat

Four puffing wheat lines (1999 crop) along with Kyle (CWAD) and CDC Dragon (Khorasan) were tested for their puffing ability. There were no significant differences in chemical composition among wheat samples, except for 99PUFF8 which had a higher protein content than the others. Puffing wheats had a slightly lighter color of the grain and flour than Kyle CWAD. Puffiness of grain was measured as the rate of expansion using deep-frying. Wheat was tempered to give four levels of moisture (7,9,12,15%) in the grain prior to deep-frying. Also, snacks made from texturized wheat flour were baked or deep-fried to measure the rate of expansion. It was hard to determine puffing ability

Table 56. Baking Quality of Einkorn Wheats for Cake[1]

Quality parameter	TM23	CDC Uno	Eink1	Eink6	Eink15	Eink31	Eink32	Cake flour[2]
Volume								
Length x width (cm)	17.6 x 2.7	17.7 x 2.8	17.6 x 2.7	17.6 x 2.7	17.5 x 2.8	17.6 x 2.8	17.6 x 2.8	17.6 x 2.9
Thick (cm)	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.8
Internal factors								
Cells uniformity	Slightly uneven	uneven	Very uneven	uneven	Slightly uneven	Slightly uneven	uneven	Even
Cell size								Small
Cell wall	thick	Slightly thick	Slightly thick	Slightly thick	Slightly thick	Slightly thick	Slightly thick	Thin
Grain	silky	silky	silky	silky	Very silky	silky	silky	Silky
Texture								
Moistness	Very moist	Very moist	Very moist	Very moist	Very moist	moist	Very moist	Slightly dry
Tenderness	Very tender	Very tender	Very tender	Very tender	tender	tender	tender	Very tender
Softness	soft	soft	soft	soft	soft	soft	Soft	Very soft
Crumb color	Creamy yellow	Creamy yellow	Creamy yellow	Creamy yellow	Creamy yellow	Creamy yellow	Creamy yellow	Bright white
Flavor	Desirable flavor (caramel)	Nutty after-taste	Sweet caramel flavor	Slightly after-taste	Slightly after-taste, sticky mouth feel	Normal flavor (good)	Normal flavor	Normal flavor (blend)

[1] Average of four cakes.
[2] Cake and pastry flour manufactured by CSP Food Co.

Table 57. Baking quality of cakes from Einkorn wheat line

Wheat sample	Volume		Internal factor								
	Length x width	Thick (cm)	Cell			Grain	Texture			Crumb color	Flavor
			Uniformity	Size	Thickness of wall		Moistness	Tenderness	Softness		
TM23	17.5x17.5	2.6	slightly uneven	slightly open	slightly thick	silky	moist	very tender	slightly firm	creamy yellow	normal
UNO	17.7x17.7	2.7	uneven	open	slightly thick	silky	moist	very tender	soft	creamy yellow	foreign
98EINK1	18.0x18.0	2.7	even	close	slightly thick	harsh	slightly dry	tender	soft	creamy yellow	normal
98EINK31	18.2x18.2	2.7	slightly uneven	slightly open	slightly thick	harsh	slightly dry	tender	soft	creamy yellow	normal
2000EINK1	17.9x17.9	2.6	even	slightly open	slightly thick	harsh	moist	very tender	soft	creamy yellow	normal
2000EINK3	18.0x18.0	2.6	slightly uneven	slightly open	slightly thick	harsh	moist	tender	soft	creamy yellow	normal
2000EINK11	18.2x18.2	2.7	slightly uneven	slightly open	slightly thick	harsh	moist	very tender	soft	creamy yellow	normal
2000EINK16	18.2x18.2	2.6	slightly uneven	slightly open	slightly thick	harsh	slightly dry	very tender	soft	creamy yellow	normal
2000EINK17	17.9x17.9	2.5	slightly uneven	slightly open	slightly thick	harsh	slightly dry	very tender	soft	creamy yellow	normal
2000EINK22	17.6x17.6	2.6	slightly uneven	slightly open	thin	silky	moist	tender	soft	creamy yellow	normal
2000EINK24	17.8x17.8	2.4	even	slightly open	slightly thick	silky	moist	tender	soft	creamy yellow	normal
Pastry flour[1]	17.7x17.7	2.9	even	normal	slightly thick	silky	moist	very tender	soft	bright white	normal

[1] Robin Hood Cake & Pastry Flour.

Table 58. Average sensory score of Einkorn cakes

	Score[1]	After-taste	Acceptability[2]
TM23	7.2	very slight	yes
UNO	6.1	lots	no*
98EINK1	6.3	some	no
98EINK31	7.0	not detected	yes
2000EINK1	6.4	slight	yes
2000EINK3	7.0	very slight	yes
2000EINK11	7.4	very slight	yes**
2000EINK16	6.9	slight	no
2000EINK17	6.9	very slight	no
2000EINK22	7.3	not detected	yes**
2000EINK24	6.3	slight	no
Pastry flour[3]	6.7	not detected	yes

[1] Overall score , 9 scale; 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely.

[2] Acceptability based on after-taste; * most unfavorable cake, ** most favorable cake.

[3] Robin Hood Cake & Pastry flour.

using deep-frying because the expansion of grain was relatively small. There was no significant difference in volume expansion among wheat samples at the same level of grain moisture. The greater expansion of grain was a result of less moisture in the grain. Snacks from 99PUFF1 and 8 had higher puffing rates (cm/g) while snack from Kyle had the highest puffing rate.

Puffing tests were conducted on four puffing wheat lines in 2001. Puffing ability was measured at a grain moisture level of 8% or 15%. Puffing rate was high in 99PUFF8, both at 8% and 15% moisture levels (Table 59). 99PUFF9 showed the lowest puffing rate at 15% moisture while Dragon showed the highest value at 8% grain moisture. There were no significant color changes in puffed grain at the two moisture levels.

Puffing wheats were processed into breakfast cereal flakes using drum drying. Cereal flakes from puffing wheats were low in starch and fat content, and high in TDF compared with the original corresponding wheats (Table 60). Flakes from 99PUFF1 were similar to Kyle and CDC Dragon flakes, having a bright yellow color. 99PUFF8 flakes had a reddish yellow color while 99PUFF9 and 99PUFF11 flakes had a greenish-yellow color (Table 61). Flakes from puffing wheats were crispy and had a favorable taste.

Table 59. Grain expansion and color of drum and puffing wheats using deep-frying [1]

Wheat sample	Volume increased (cc)[2]	
	8% moisture	15% moisture
Kyle	7.5 (1.60)	6.0 (1.46)
Dragon	8.0 (1.62)	5.0 (1.36)
Puff 1	7.0 (1.52)	6.0 (1.43)
Puff 8	7.5 (1.60)	6.5 (1.48)
Puff 9	6.5 (1.50)	5.0 (1.36)
Puff 11	6.5 (1.50)	5.5 (1.39)

Wheat sample	HunterLab color[3]								
	Intact grain			Puffed grain					
	moisture (as is)			8% moisture			15% moisture		
	L	a	b	L	a	b	L	a	b
Kyle (Trt.1)	40.2	6.96	13.98	36.55	10.17	14.53	37.03	9.79	14.40
Dragon (Trt.2)	39.00	6.92	13.31	38.38	10.60	15.82	37.93	10.32	15.21
Puff 1 (Trt.3)	38.95	6.27	12.66	36.56	10.68	14.93	36.74	10.11	14.43
Puff 8 (Trt.10)	37.05	7.05	12.56	38.00	10.84	15.77	38.22	10.32	15.21
Puff 9 (Trt.11)	37.56	6.24	12.06	36.44	10.67	14.78	35.13	9.78	13.60
Puff 11 (Trt.13)	37.95	6.44	12.33	34.43	9.96	13.53	35.43	9.63	13.60

[1] Whole grain was puffed using deep-frying at 200EC for 1 min.
[2] Values in parenthesis indicate the expansion rate; volume increased (cc)/initial volume (cc) of grain.
[3] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue).

Table 60. Chemical composition of flour and drum-dried flake from durum wheat and puffing wheat lines

	Protein (%)	Starch (%)	Crude fat (%)	Ash (%)	TDF (%)[1]
Flour					
Kyle	17.36	76.9	0.93	0.72	2.80
Dragon	17.00	77.4	0.79	0.77	2.94
99Puff 1	16.96	76.0	0.78	0.83	3.13
99Puff 8	16.51	76.4	0.80	0.78	2.86
99Puff 9	17.41	75.4	0.74	0.87	3.08
99Puff 11	17.54	77.9	0.77	1.02	2.92
Drum-dried flake					
Kyle	16.95	64.8	0.32	0.77	3.60
Dragon	16.76	66.5	0.25	0.76	4.53
99Puff 1	16.69	67.0	0.23	0.82	4.51
99Puff 8	16.39	65.6	0.29	0.79	4.06
99Puff 9	17.20	57.9	0.30	0.84	6.03
99Puff 11	17.12	62.1	0.26	0.95	4.78

[1] Total dietary fiber (%).

Table 61. color comparison of flour and drum dried samples of drum wheat and puffing wheat lines

Samples	HunterLab Color[1]		
	L	a	b
Flour			
Kyle	87.08	0.40	17.95
Dragon	86.16	0.82	16.90
99Puff 1	85.84	0.74	16.84
99Puff 8	86.05	0.78	16.32
99Puff 9	85.26	0.83	16.50
99Puff 11	84.78	1.00	17.25
Drum-dried flake			
Kyle	78.01	3.16	20.97
Dragon	77.81	3.00	20.84
99Puff 1	77.87	2.95	20.86
99Puff 8	75.96	4.03	20.80
99Puff 9	79.29	2.08	19.59
99Puff 11	77.44	2.88	20.89

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue).

CONCLUSIONS

Progress has been made with the selection of an awnless spring spelt breeding line with winter spelt protein profile. This promising line (99SPELT9) from our first cycle of crosses was evaluated for a first year in a Registration Test in 2001. A number of other promising spelt breeding lines are currently under evaluation. We have identified a number of partial-threshing einkorns with good cookie and baking quality. These lines are lower-yielding than the hulled einkorn control. Experimental lines designed to provide baking quality emmer x durum derivatives were advanced rapidly via greenhouse and winter nursery multiplication. These lines were first yield-tested in 2000. The first semidwarf puffing wheats were yield-tested in 1999. These lines were lower-yielding than the durum check as a result of leaf disease. These lines have the required seed size (20 mg heavier than durum) and shape.

Alternative wheats had starch characteristic and protein composition varying from one species to the next. Khorasan proteins showed some similarities to durum proteins, while CDC Bavaria soft spelt was somewhat close to CWRS common wheat. The similarities between Khorasan wheat and durum starches as well as between CDC Bavaria soft spelt and CWRS common wheat starches indicate the potential of Khorasan wheat as a durum or pasta alternative wheat and soft spelt as an organic bread wheat. The unique characteristics exhibited by einkorn starch associated with high protein and carotene contents and low gluten strength will make this wheat a unique in some soft wheat applications.

Baking quality evaluations were made on Spelt, Einkorn and Emmer wheats. Most of the breads from Spelt x common wheat lines (1999 crop) were dense and had a lighter crust color. Spelt breads from the 2000 crop had good loaf volumes, and were comparable with the common wheat bread. Spelt bread, especially from 2000SPELT20, was high in loaf volume and had a comparable white crumb color to the control bread.

Spelt x common wheat lines have potential in noodle and pasta production. Even though spelt wheat, except CDC Bavaria, had a slightly yellowish color in salted white noodles, texture profile of the product was comparable to that of soft wheat, which is widely used for noodle production. Noodles had a good texture profile and scored high in eating quality due to appearance and mouth feel. Most of the pasta from selected spelt wheats (4 lines, 1999 crop) was acceptable and scored higher than pasta from semolina. Noodles from selected spelt wheats in 2000 were comparable in texture profile with soft wheat noodles even though spelt noodles were slightly softer and gummier. There were no visual differences between spelt and soft wheat noodles. Pasta products prepared from selected spelt wheats were comparable with durum pasta. From the sensory evaluation, the yellowness and a certain amount of firmness in mouth-feel were desirable factors in the spelt pasta products.

With the addition of a natural improver, ascorbic acid, poor bread baking quality of emmer wheat was greatly alleviated, resulting in a higher loaf volume and better crumb texture than control breads. On the other hand, with a long fermentation time, breads from emmer x durum wheat lines produced big oven spring and larger loaf volumes than common wheat bread. Emmer x durum wheat breads had a fine, soft and elongated grain of the crumb structure and had a yellowish crumb compared to the control bread. Malted emmer wheat had slightly darker color and had high enzyme activities, including ∀-amylase and proteolytic enzymes.

Most einkorn wheats had excellent cookie baking qualities, including a desirable yellow crumb color, volume and texture. However, some of the einkorn lines had an after-taste in the product. Einkorn cakes were moist, tender, and creamy yellow in crumb color. Even though einkorn cakes showed very good quality, some of cakes had the undesirable after-taste.

Cereal flakes from puffing wheat were crispy, slightly reddish or greenish yellow in color, and had a favorable taste. Puffing ability was measured at several grain moisture levels. The difference in puffing rate was relatively small among puffing wheats.

IMPACT ON SASKATCHEWAN AGRICULTURE

The utilization of alternative wheats in food product will provide new markets, introduce new products to the food industry and will diversify the wheat industry.

TECHNOLOGY TRANSFER

Abdel-Aal, E.S.M., F.W. Sosulski and P. Hucl. 1998. Origins, characteristics, and potentials of ancient wheats. CFW. 43:763-709-715.

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E.S.M. Abdel-Aal, P. Hucl and F.W. Sosulski. 1999. Starches from primitive wheats: I. Extraction efficiency, granule size distribution and composition. AACC Annual Meeting, Seattle WA, November 1999.

E.S.M. Abdel-Aal, P. Hucl and F.W. Sosulski. 1999. Starches from primitive wheats: II. Thermal and structural properties. AACC Annual Meeting, Seattle WA, November 1999.

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ITEM "B". Deviations from original work plan - NIL

ITEM "C". Achievements – Agronomic evaluation, starch and protein characteristics of alternative wheats and quality evaluation of their end products.

ITEM "D". Equipment – NIL

ITEM "E". Personnel

C. Petruka (May 1 - September 30, 1998) – 50%
(Summer Res. Asst.)

Z. Rezaei (September 1 – 30, 1998) – 100%
(Res. Asst)

S. Zou (May 19, 1998 – September 30, 2001) – 50%
(Res. Techn)

N.Y. Jai (July 1, 1999 – December 31, 2001) – 50%
(Res. Techn)

H. Braitenbach (January 1 – June 30, September 1 – December 31, 1999) – 100%
(Res. Techn) (January 1 – June 30, September 1 – December 31, 2000) – 100%
(January 1 – June 30, September 1 – December 31, 2001) – 100%

E-S.M. Abdel-Aal (April 1, 1998 - June 30, 1999) – 20%
(Res. Sci)

H.L. Han (July 1, 1999 – August 4, 2000) – 33%
(PRA) (February 4, 2001 – May 31, 2001) – 33%

Other sources of funding:

P. Hucl (April 1, 1998 – June 30, 1999) – 2%
(July 1, 1999 – December 31, 2001) – 5%

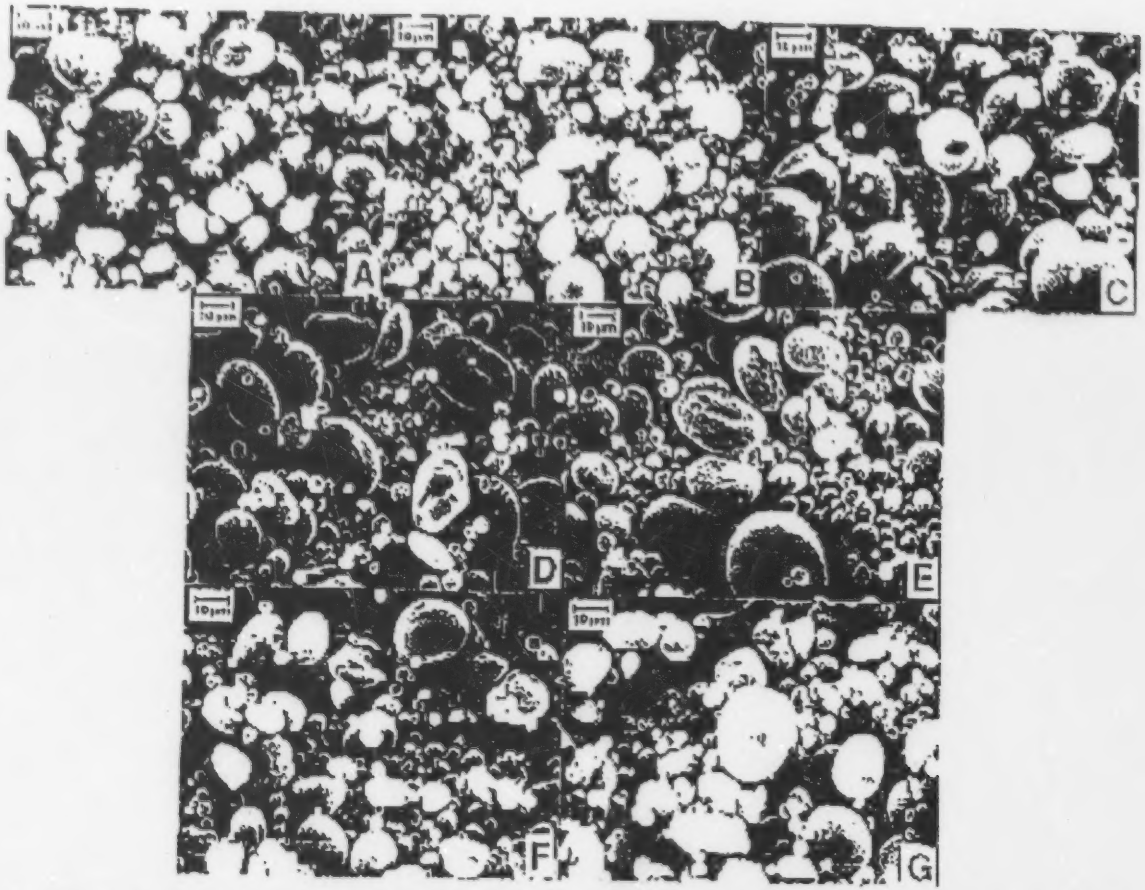

Fig. 1.SEM-photomicrographs of alternative and check wheat starches: (A) einkorn, (B) emmer, (C) Khorasan, (D) hard spelt, (E) soft spelt, (F) durum and (G) common wheat

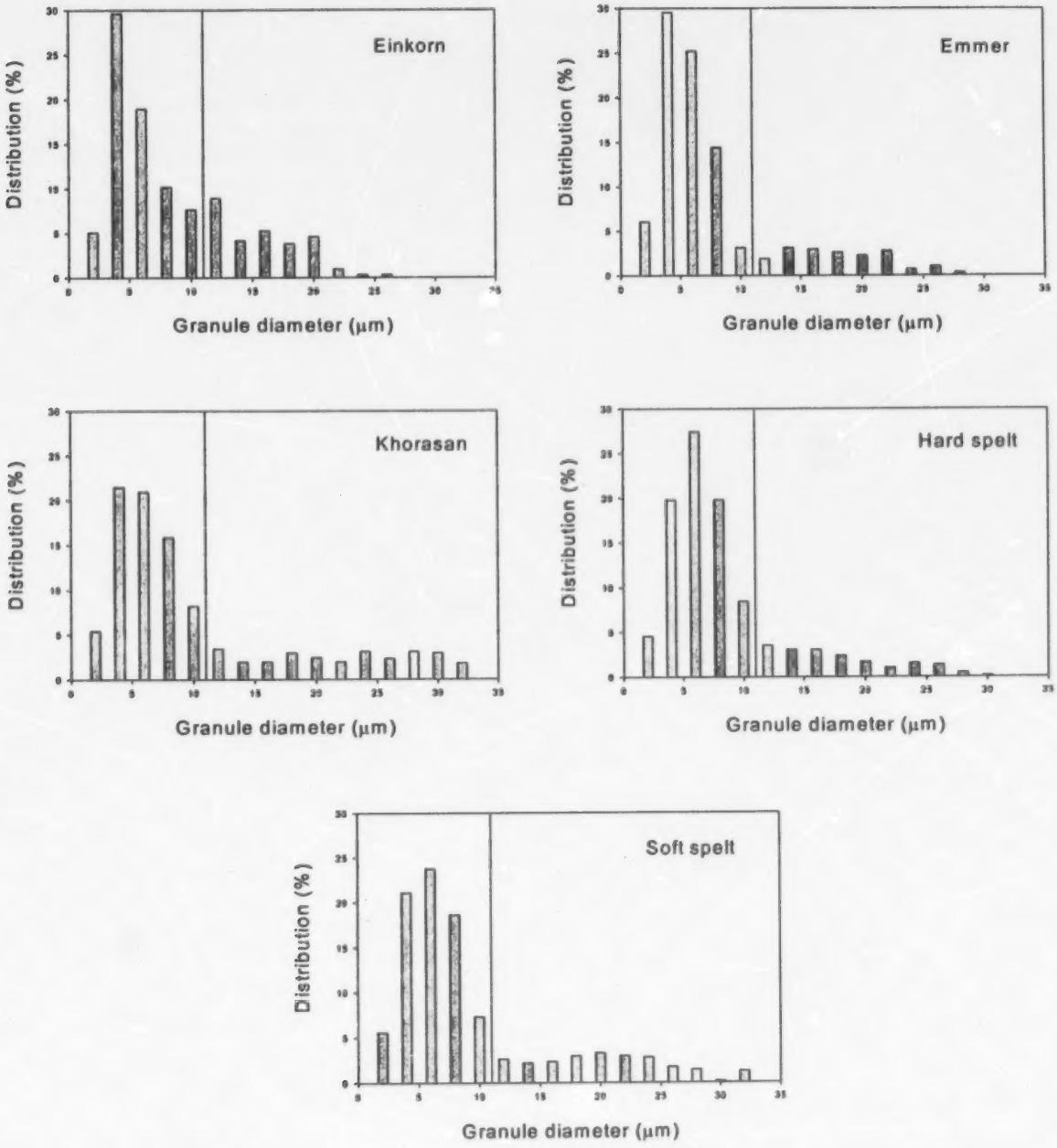

Fig. 2. Granule size distribution of alternative wheat starches

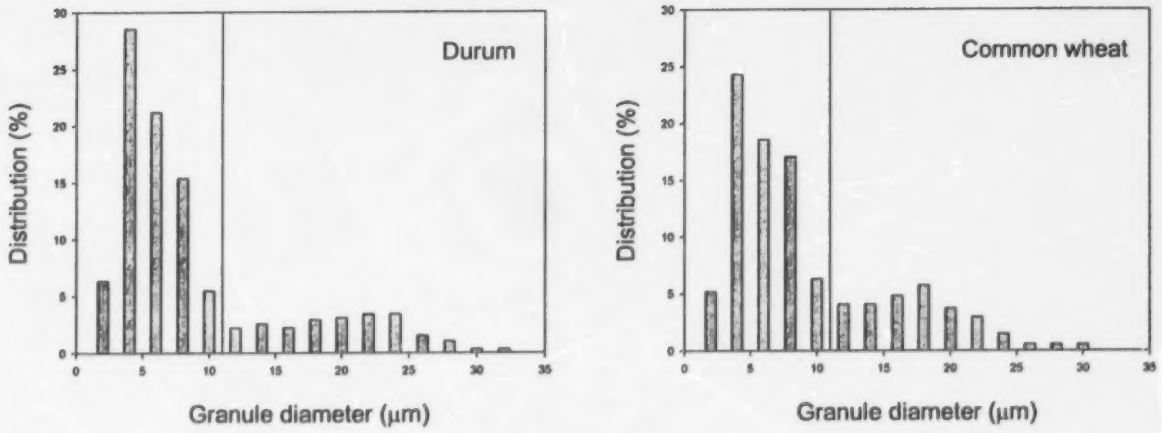

Fig. 3. Granule size distribution of check wheat starches

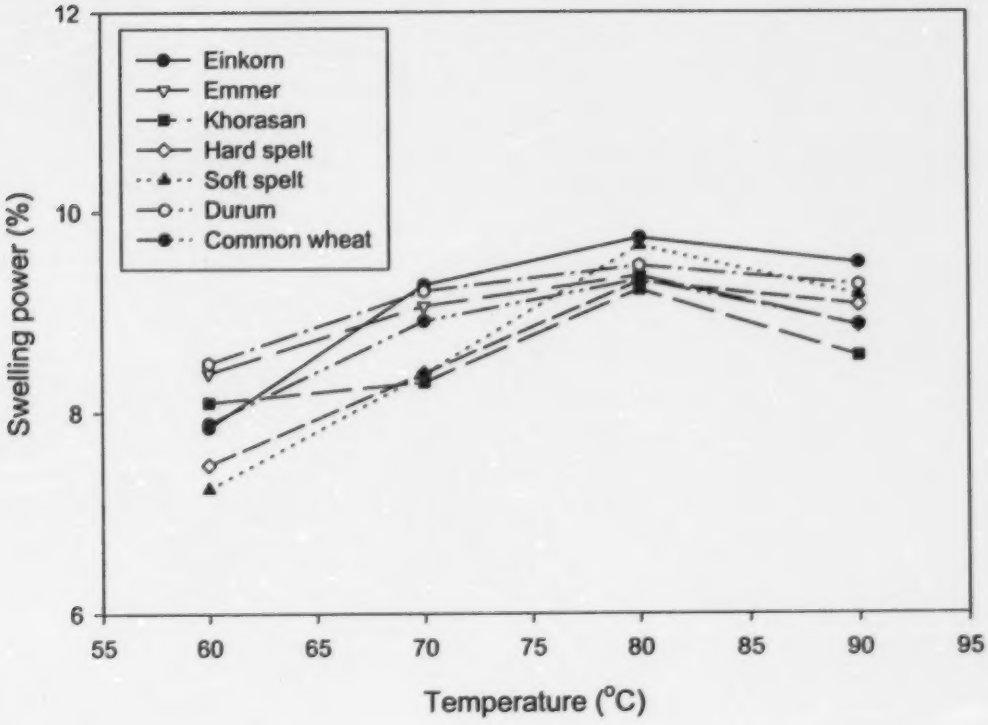

Fig. 4. Swelling power of alternative and check wheat wholemeals

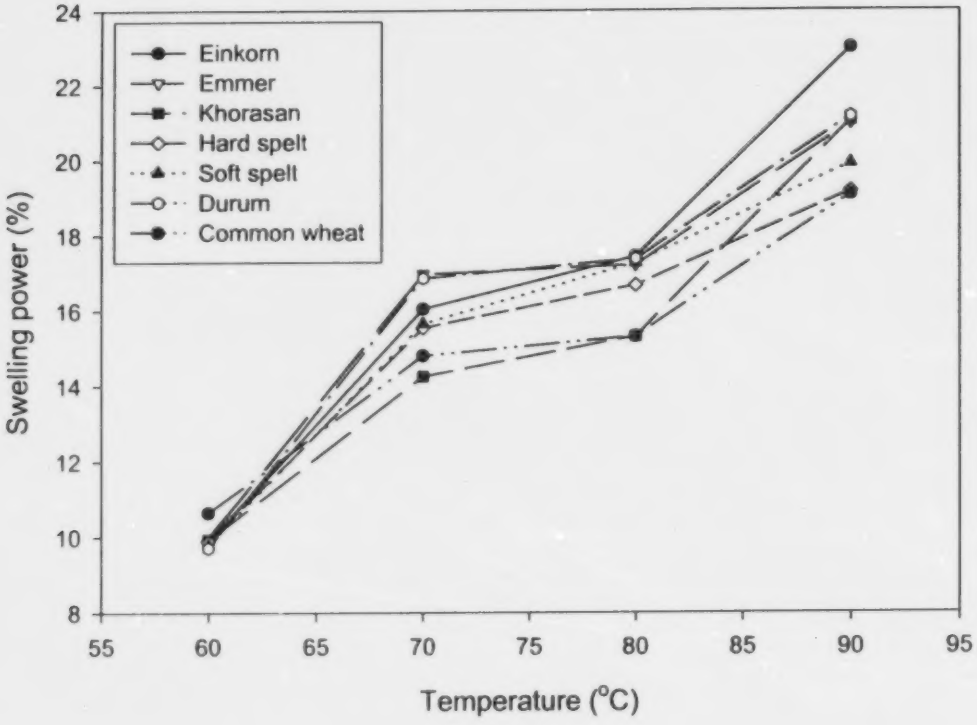

Fig. 5. Swelling power of alternative and check wheat starches

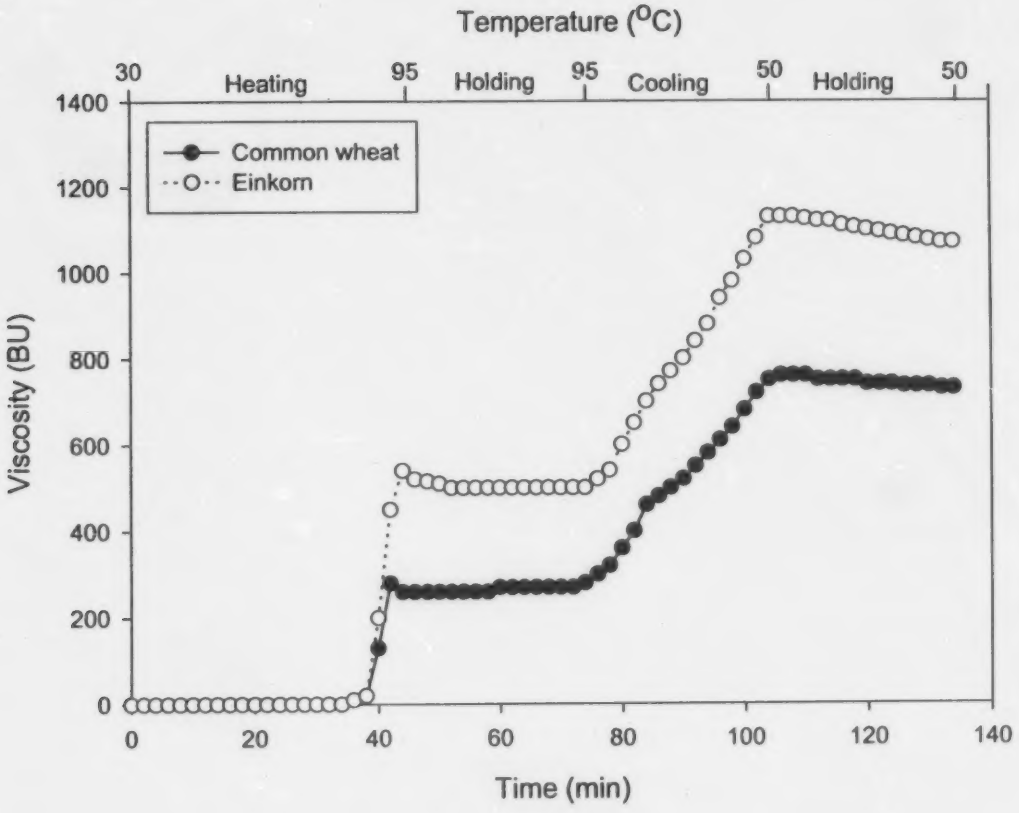

Fig. 6. Visco/amylograph curves of einkorn and common wheat starches

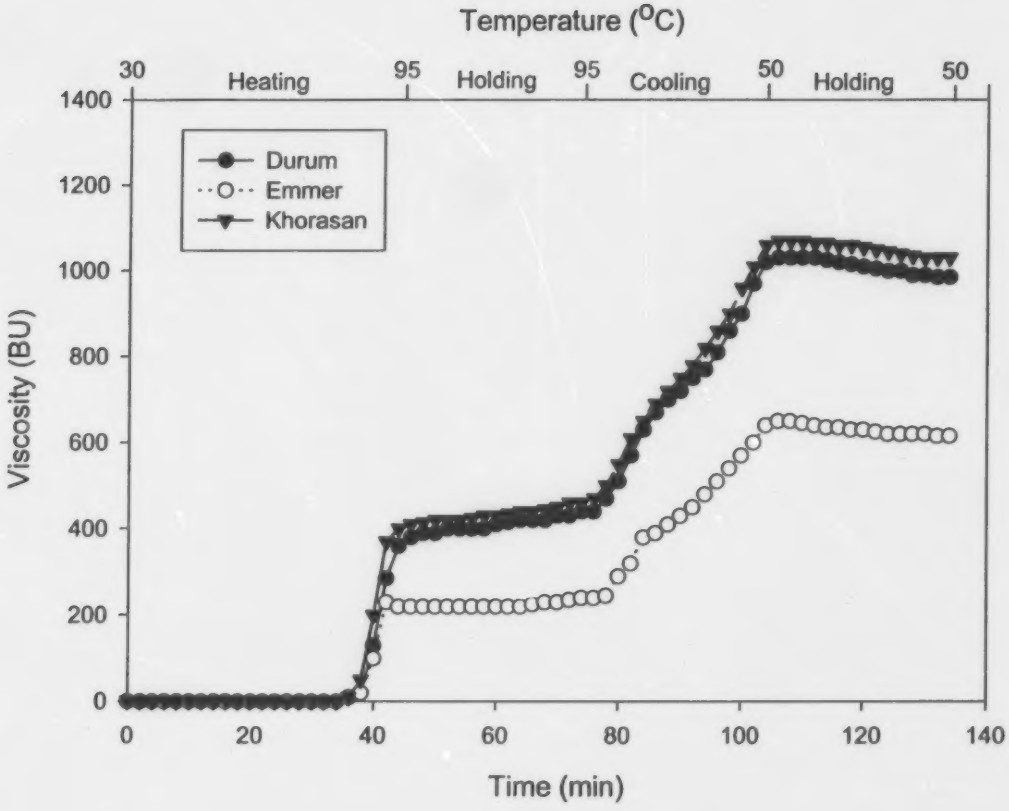

Fig. 7. Visco/amylograph curves of emmer, Khorasan and durum wheat starches

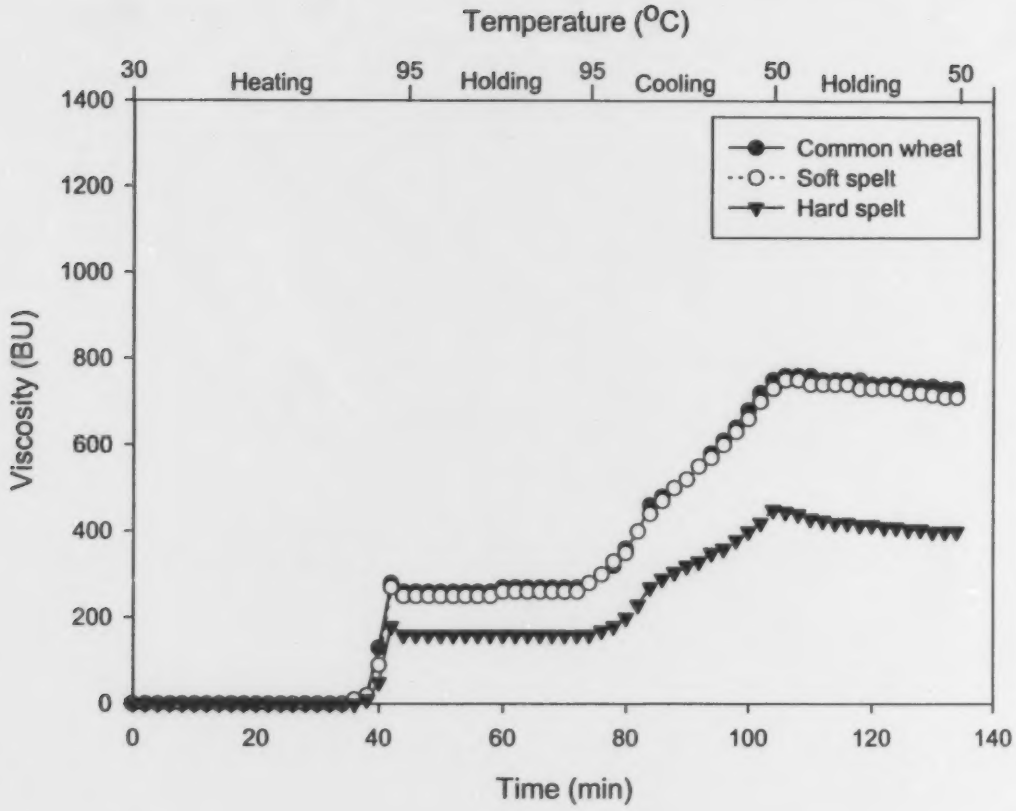

Fig. 8. Visco/amylograph curves of soft and hard spelt and common wheat starches

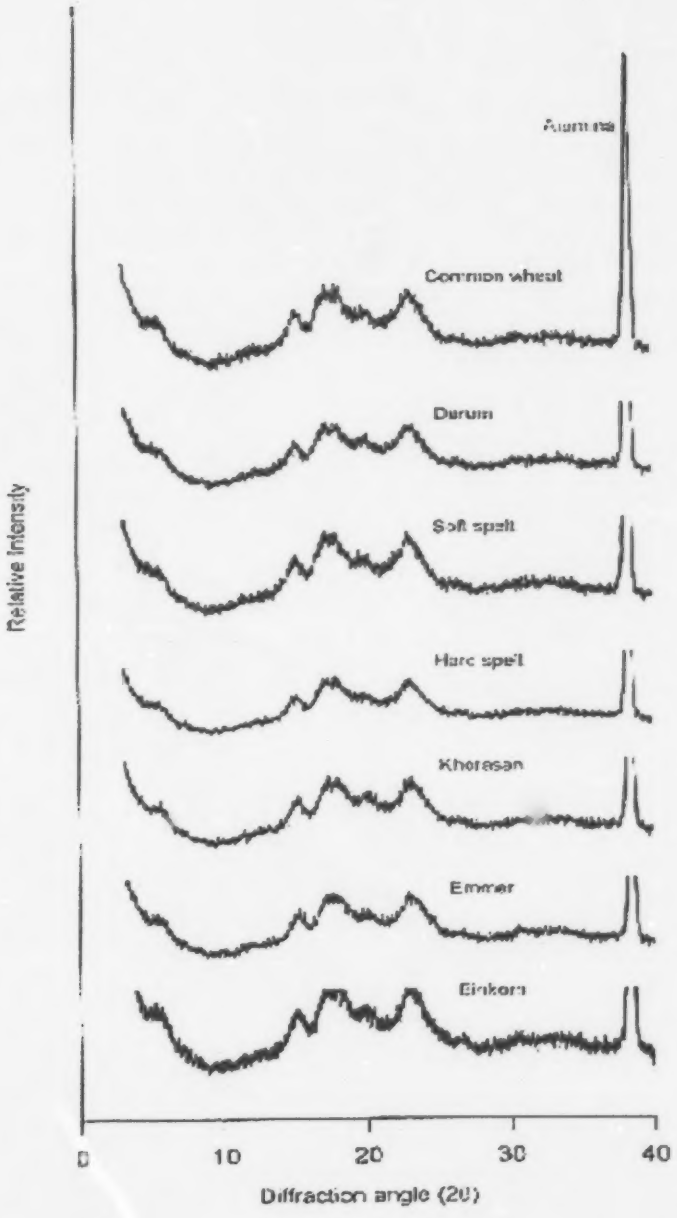

Fig. 9. X-ray diffraction patterns of alternative and check wheat starches

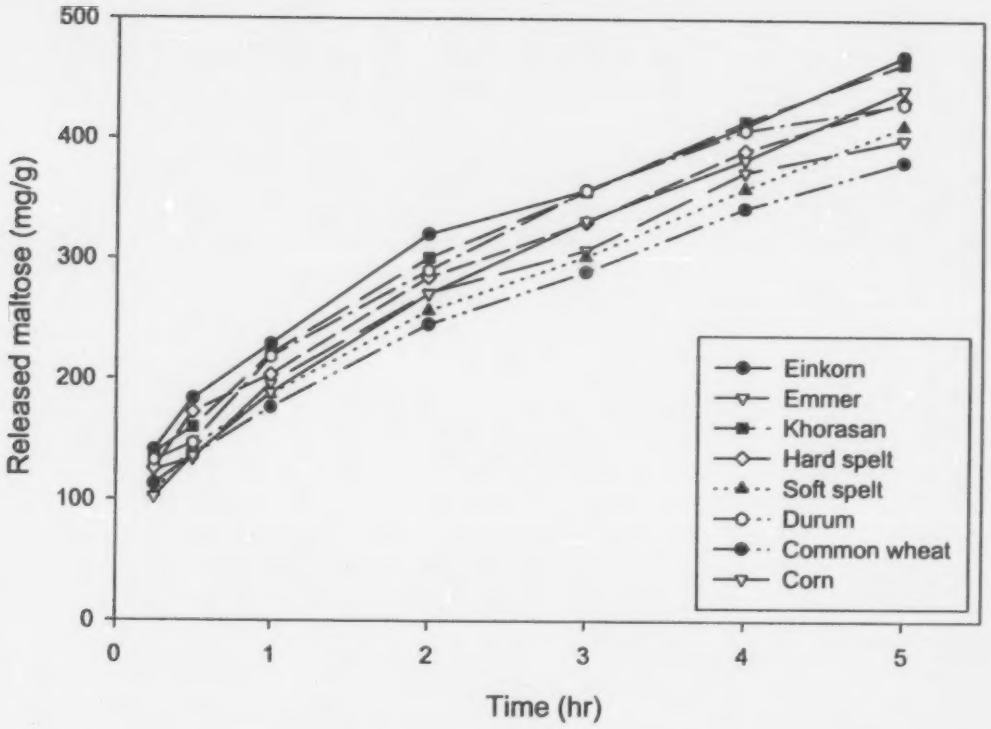

Fig. 10. In vitro digestibility of alternative and check wheat starches over different incubation times

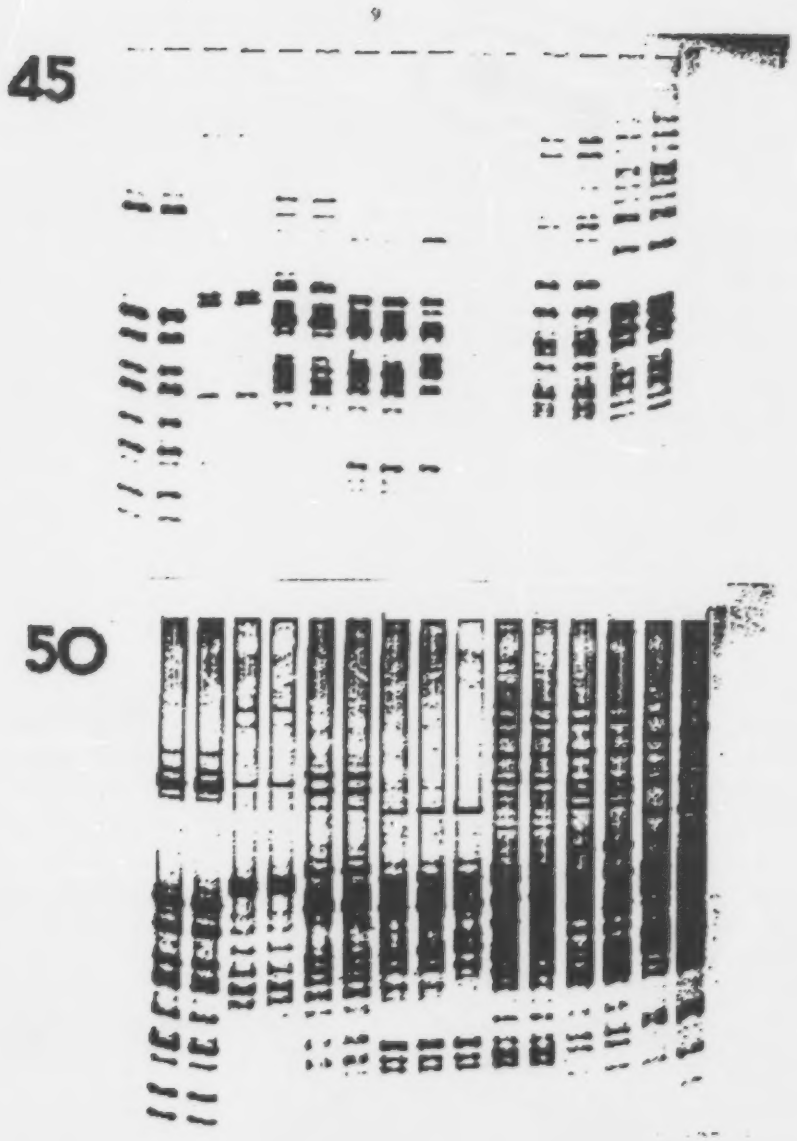

Fig. 11 A-PAGE gliadin composition. From left to right: einkorn (1,2), soft wheat (3,4), emmer (5,6), Khorasan (7,8), durum (9), hard spelt (10,11), soft spelt (12,13) and common wheat (14,15). Photo #45: ethanol soluble and #50: propanol soluble.

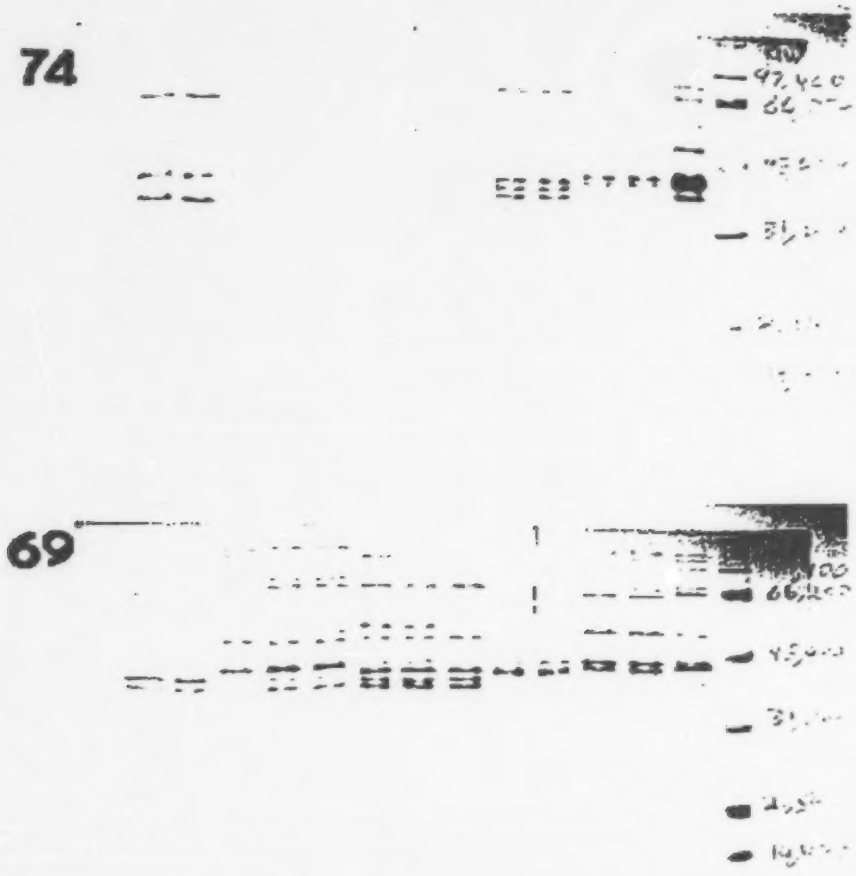

Fig. 12. SDS-PAGE gliadin composition. From left to right: einkorn (1,2), soft wheat (3), emmer (4,5), khorasan (6,7), durum (8), hard spelt (9,10), soft spelt (11,12), common wheat (13) and protein marker (14). Photo #74: ethanol soluble and #69: 50% propanol soluble.

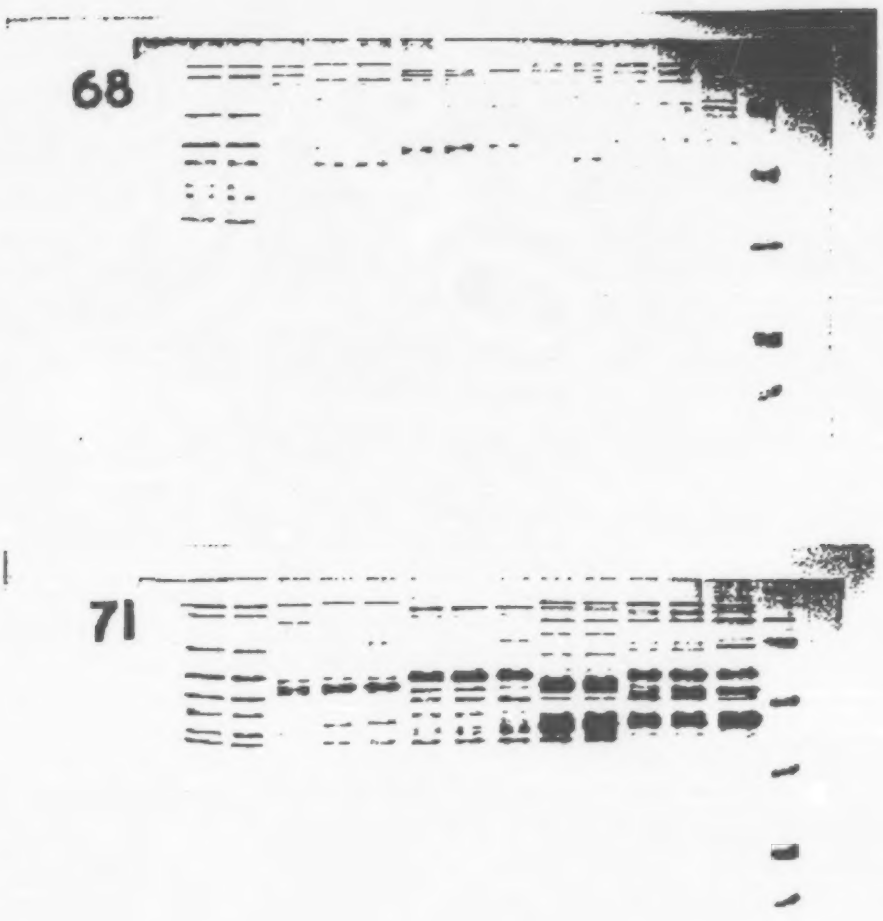

Fig. 13. SDS-PAGE glutenin composition. From left to right: einkorn (1,2), soft wheat (3), emmer (4,5), khorasan (6,7), durum (8), hard spelt (9,10), soft spelt (11,12), common wheat (13) and protein marker (14). Photo #68: SDS soluble and #71: propanol-DTT soluble.

Fig. 14. SDS-PAGE glutenin composition. From left to right: einkorn (1,2), soft wheat (3), emmer (4,5), khorasan (6,7), durum (8), hard spelt (9,10), soft spelt (11,12), common wheat (13) and protein marker (14). Photo #72: propanol-DTT-acetic acid soluble.

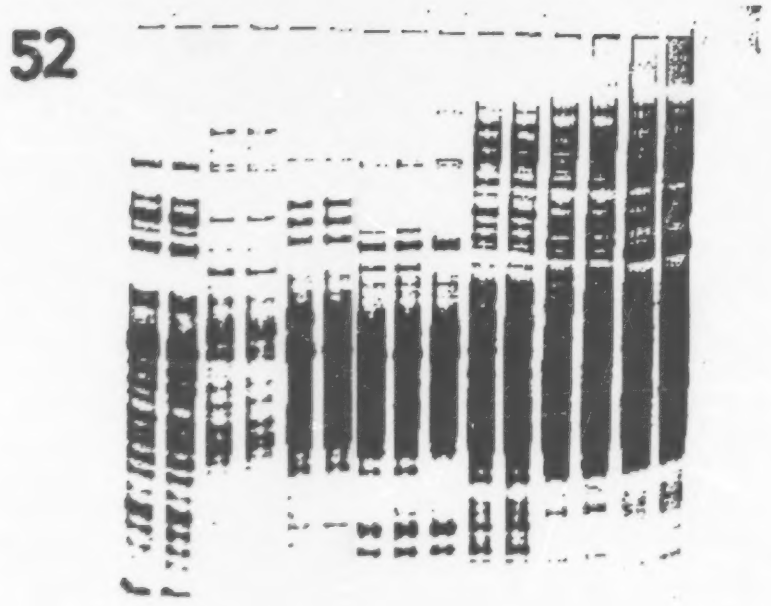

Fig. 15. A-PAGE of total protein composition. From left to right: einkorn (1,2), soft wheat (3,4), emmer (5,6), khorasan (7,8), durum (9), hard spelt (10,11), soft spelt (12,13) and common wheat (14,15). Photo #52: propanol-DDT-acetic acid soluble.

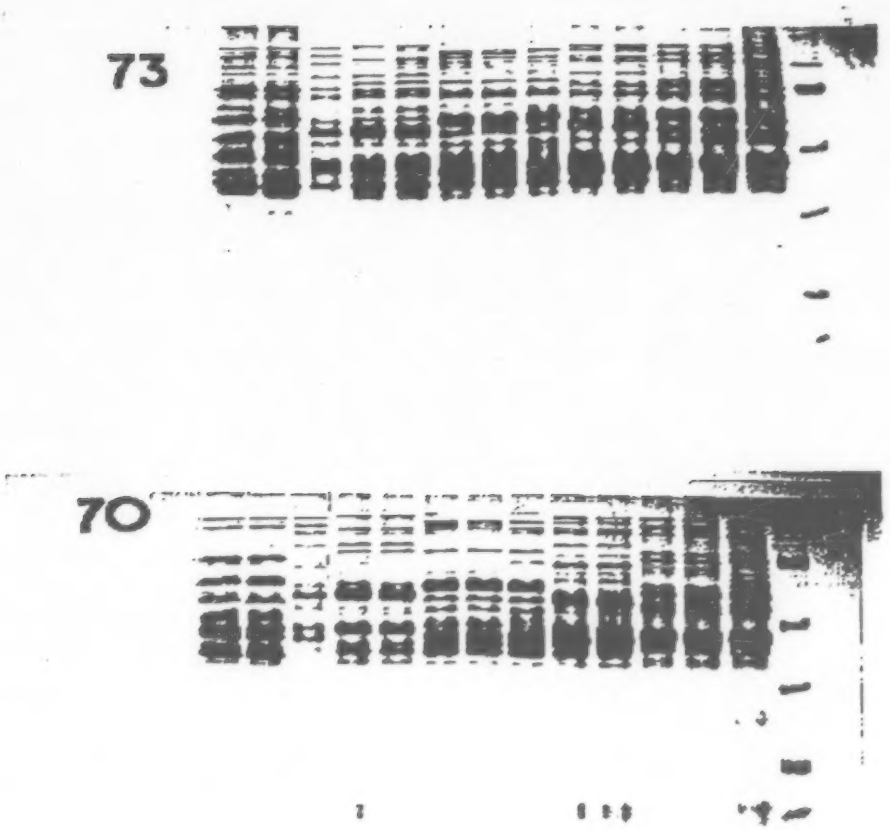

Fig. 16. SDS-PAGE of total protein composition. From left to right: einkorn (1,2), soft wheat (3), emmer (4,5), khorasan (6,7), durum (8), hard spelt (9,10), soft spelt (11,12), common wheat (13) and protein marker (14). Photo #73: SDS soluble and #70: propanol-DTT-acetic acid soluble.

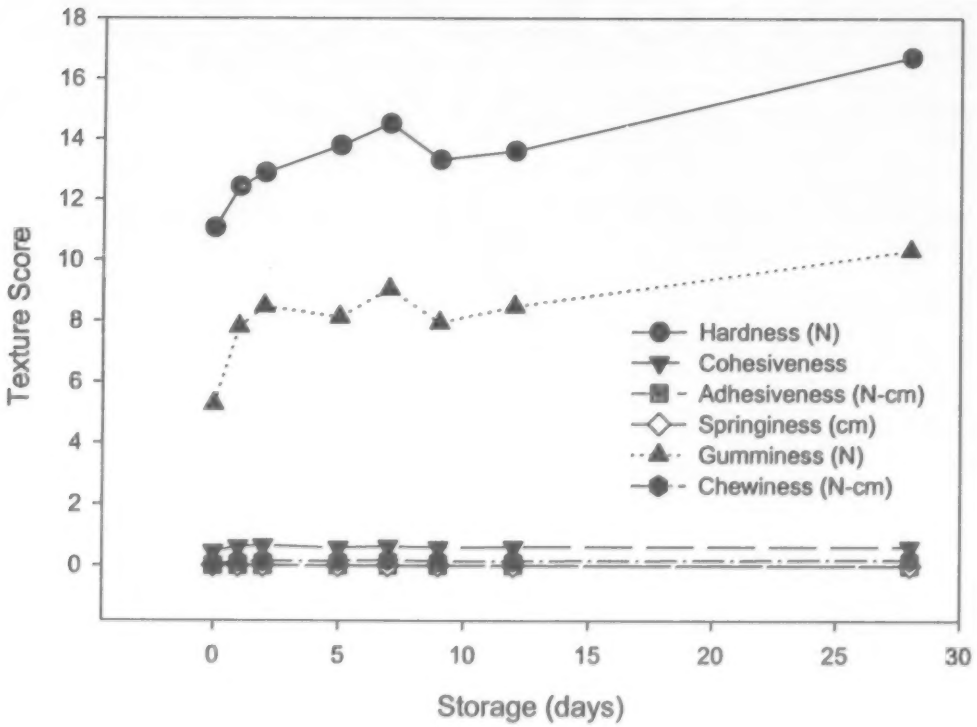

Figure 17. Texture profile of dried noodle from Katepwa at the period of storage.

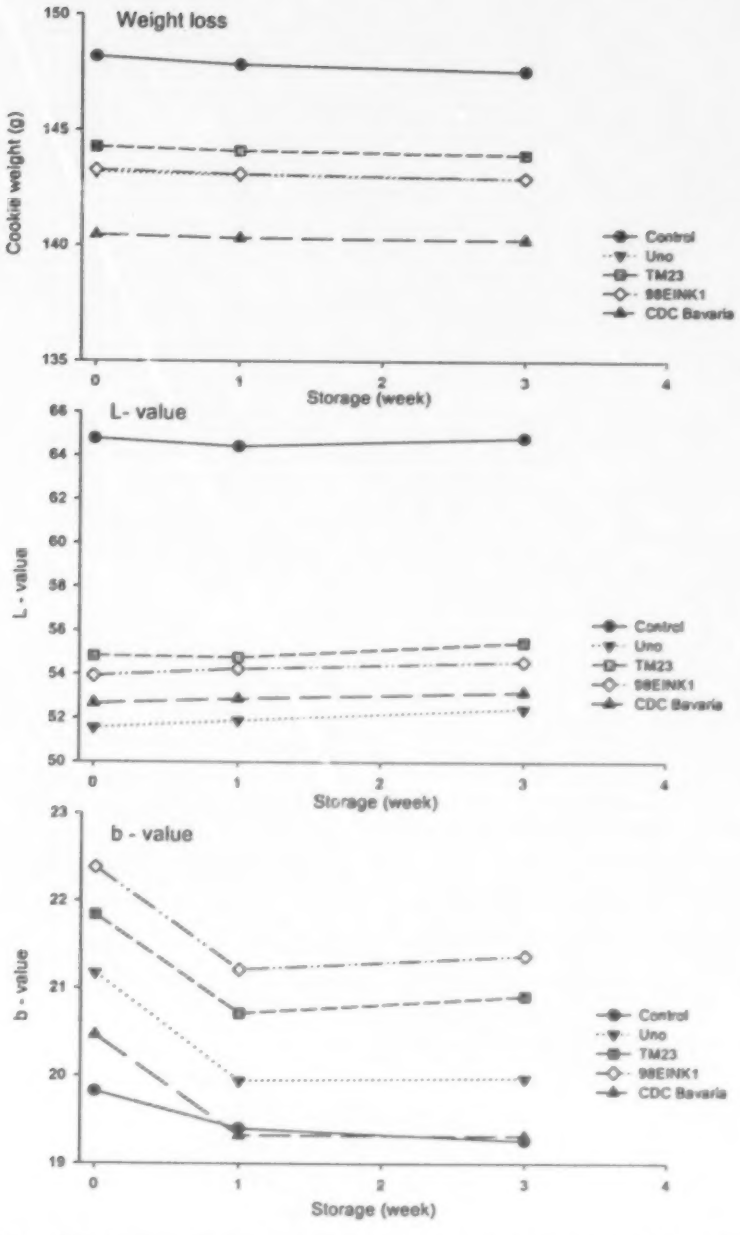

Figure 18. Effect of storage time at room temperature on weight and color of Einkorn cookies. Control, commercial cake and pastry flour; Uno, TM23, and 98EINK1, Einkorn wheat; CDC Bavaria, Spelt wheat.